Canada Mortgage and Housing Corporation

Société canadienne d'hypothèques et de logement

CMHC

BASEMENT CONDENSATION:

FIELD STUDY OF NEW HOMES IN WINNIPEG

Prepared for

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Corporation

by

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

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CMHC SUMMARY

Background:

CMHC was requested by the Manitoba Home Builders' Association to assist in investigating a recent increase in homeowner complaints due to basement condensation in new homes and the resulting damage to finishes.

Objectives:

To determine the causes of excessive basement condensation in new homes in Winnipeg, to recommend appropriate remedial action and to recommend construction practices which will avoid or reduce such problems.

Methodology:

The consultant examined 14 dwellings representing a cross section of new and old dwellings, some with and some without basement moisture problems. Wall surface and air temperatures, relative humidities and outdoor conditions were monitored, and the construction histories of each house were documented. Remedial measures were undertaken where condensation problems were severe.

Conclusions:

It was determined that many homes have sufficiently cold basement walls in spring and summer to create the potential for the condensation of humid summer air. Such problems do not appear in most older homes, since the walls have dried and can absorb small amounts of condensation. In newer homes, especially those where concrete foundations have been poured during the winter, the walls are still saturated and have no potential for moisture storage, thereby resulting in condensation pools.

The recent practice of fully insulating and finishing the interior of basement walls appears to have slowed down the normal concrete drying process and made the problem worse.

Recommendations:

For remedial measures, framed basement walls should be opened up to expose the concrete to good drying conditions for a period of several months. Upon closing the wall, a properly sealed air/vapour barrier should be installed to prevent the circulation of moist house air behind the insulation.

For new construction, basement walls should ideally be insulated on the exterior to raise the interior surface temperatures. If insulating is to be done on the interior, the walls should be framed but not insulated or finished for approximately one year after completion of construction to allow the concrete walls to fully dry (this would require a change in the way building codes are administered). In addition, a continuous air/vapour barrier should be installed to block the flow of moist air through the wall cavity, and moisture levels should be reduced during winter construction.

EXECUTIVE SUMMARY

The Manitoba Homebuilders' Association and the New Home Warranty Program of Manitoba Inc. have reported many instances of homeowners experiencing basement condensation problems in new homes. A field investigation of Winnipeg houses was carried out during the May to September period of 1987 with the three objectives of determining the causes of excessive basement condensation in new homes, recommending appropriate remedial action, and suggesting construction practices which would avoid or reduce such problems.

Fourteen houses which either exhibited a moisture problem or illustrated some other detail relevant to the condensation question were examined. Visual inspections of the grounds, exterior and interior of each house were made, particular attention being directed to drainage, the foundation, the basement interior, and the condensation problem. Spot measurements and continuous monitoring records of air temperature and moisture in the basement, on other interior levels, and outdoors were compared to concrete wall and floor surface temperatures and to the locations of surfaces where condensation was occurring.

The houses with summer basement condensation had concrete wall surface temperatures about the same as older and drier conventional basements and these were close to the dewpoint temperatures of normal basement air.

The moisture contents of air in the basements were the same as, or only slightly higher than, seasonal outdoor values for all but the wettest basements. When standing water had disappeared and batt insulation in the basement was no longer damp, the 10-to-30-percent higher air moisture levels in the wettest basements could be reduced to the typical seasonal values measured in other houses through ventilation or other dehumidifying means. Under such drying conditions and with insulation removed to expose the concrete, condensation on the lower walls and in the corners persisted in the sample houses for weeks to months.

The field observations imply that many Winnipeg houses, old and new, operate for part of the year with some interior concrete surfaces cool enough to promote condensation, yet little or no condensation occurs. However, new houses constructed during cold weather according to normal local building practices, with insulation applied on the interior over the full height of the concrete foundation wall, are susceptible to a significant condensation problem, particularly during the first summer of occupancy. The difference appears to be in the amount of drying experienced by the concrete since the time of construction. Non-saturated concrete may have some capacity to absorb and store short-term excesses of moisture in the air contacting it, regardless of whether more of that moisture comes from humid basement air or is released from the fresh concrete. Saturated concrete or any low-permeance dampproofing materials located on the cold side of the insulation do not have such storage capacity.

For new house basements in which problem condensation has occurred, it is recommended that the framed wall be opened up to expose the concrete, and that good drying conditions be provided in the basement for one to several months before the interior framed wall is restored.

The basement condensation phenomenon could become more widespread if full-height insulation were to become more common across the country. Therefore it is proposed that, if the concrete foundation wall is to be insulated on the interior, it should be left open for some time after construction (e.g., as much as one year) before completing the interior finish. Other mitigative or preventive construction practices suggested include:

(a) insulation of foundations on the exterior,
(b) the maintenance of low interior moisture levels during winter construction,
(c) installation of a properly sealed air/vapour barrier in the basement, and
(d) as an alternative to (c), provision of a barrier to air flow somewhere along the flow path of air through the wall cavity.

The undertaking of a program of winter observation of condensation-related factors and susceptible new houses is recommended as a complement to the present summer field study in raising the level of understanding of the basement condensation problem, and it is suggested that beneficial construction practices be trial-tested.

TABLE OF CONTENTS

Section		Page
1.0	INTRODUCTION	1
2.0	PROJECT OBJECTIVES	1
3.0	PROJECT METHODOLOGY	2
4.0	RESULTS AND FINDINGS	4
	4.1 CONTEMPORARY CONSTRUCTION PRACTICES AND THE TYPICAL HOUSE BASEMENT	4
	4.2 THE BASEMENT CONDENSATION PHENOMENON	11
	4.3 NEW HOME BASEMENT CONDENSATION IN WINNIPEG . . .	13
	4.4 BASEMENT CONDENSATION MECHANISMS IN THE STUDY HOUSES	18
	4.4.1 Wall Temperatures	18
	4.4.2 Air Moisture Content	20
	4.4.3 Relation Between Air Moisture Levels and Observed Wall Condensation	24
5.0	CONCLUSIONS	29
6.0	RECOMMENDATIONS	30
	6.1 REMEDIAL MEASURES	30
	6.2 CONSTRUCTION PRACTICES	32
	6.3 FURTHER RESEARCH	35
APPENDIX A	PROJECT HOUSE DESCRIPTIONS AND MONITORING DATA	37

LIST OF TABLES

Table		Page
1	SINGLE-FAMILY RESIDENTIAL BUILDING PERMITS ISSUED FOR CITY OF WINNIPEG AND ADDITIONAL ZONE 09/85-08/87 . . .	5

LIST OF FIGURES

Figure		Page
1	TYPICAL WINNIPEG NEW HOUSE BASEMENT CONSTRUCTION . . .	6
2	BASEMENT CONDENSATION IN WINNIPEG NEW HOUSES: WETTED SURFACES	15
3	MOISTURE CONTENT OF WINNIPEG OUTDOOR AIR AND BASEMENT AIR OF SELECTED PROJECT HOUSES	22
4	RELATION BETWEEN WALL TEMPERATURES, BASEMENT AIR, AND WETTED SURFACES	26
5	BASEMENT WALL CAVITY AIR CIRCULATION PATTERN AND MITIGATIVE MEASURE	34

1.0 INTRODUCTION

The Manitoba Homebuilders' Association and the New Home Warranty Program of Manitoba Inc. have reported many instances of homeowners experiencing basement condensation problems in new homes. Typically the homeowner is alarmed at the occurrence of a phenomenon not encountered in previous residences, and the presence of water in the basement is taken as being indicative of leakage from outside and a problem with the foundation. Often, moisture and mildew damage to possessions placed in the basement has shown up soon after occupancy. Since a basement is often finished by the builder or shortly after occupancy by the owner, installed floor coverings, furnishings and wall finishes can also be at risk of damage.

The occurrence of basement condensation in Manitoba in summer and winter is not a new phenomenon, but its prevalence in recent years in new houses has increased. Given that building practices have been and are evolving in reponse to more stringent requirements for energy efficiency and airtightness, this may be indicative of an unanticipated side effect. There are currently various points of view regarding the nature of the basement condensation and how it can be avoided. The study of the problem in Winnipeg basements which is reported herein attempts to improve the level of understanding of the mechanisms involved, and to provide suggestions to eliminate the problem or control the phenomenon's impact on the home.

2.0 PROJECT OBJECTIVES

(a) To determine the causes of excessive basement condensation in new homes in Winnipeg,

(b) To recommend appropriate remedial action, and

(c) To recommend construction practices which will avoid or reduce such problems.

3.0 PROJECT METHODOLOGY

A case study investigation of the condensation phenomenon was undertaken during the May to September period of 1987. Fourteen houses which either exhibited a moisture problem or illustrated some other detail relevant to the condensation question were examined. Of the nine cases in the sample with moisture problems, all were identified as such by their concerned occupants and were provided by direct contact or by referral through the New Home Warranty Program of Manitoba or through the builders involved. The latter were the sources of the majority of the houses. All units were typical of contemporary local building practices, with cast-in-place reinforced concrete foundations on spread footings and with foundation walls insulated on the interior.

Of the five other cases examined, two were older houses which could be considered to be representative of the situation where the residual effects of construction and initial moisture condition of materials would be negligible. Two others were built in 1986 to R-2000 standards, with foundation insulation on the exterior. The final unit of the sample was of very recent vintage (summer 1987) and was included to represent the results of construction under favourable weather conditions.

All of the above houses are described in detail in Appendix A, with the results of monitoring also appearing therein and analysis of findings appearing in Section 4 below. In addition to the fourteen homes making up the final study sample, approximately ten more units with basement condensation were considered for inclusion but were set aside following site visits or interviews with the occupants which indicated that their symptoms and problems were similar to those already being monitored.

One or more site visits were made to each of the sample houses during which the grounds, exterior and interior were examined, and particular attention was directed to drainage, the foundation, the basement interior, and the condensation problem. Spot measurements of air temperature/moisture conditions outside, in the basement, and on other interior levels were made during each visit, using a manual sling psychrometer (wet bulb and dry bulb temperatures). Outdoor temperatures and humidity levels obtained in this way were found to correspond almost exactly to simultaneous measurements reported by Environment Canada for the nearest major weather station, Winnipeg International Airport. As a result, sling psychrometer data describing exterior and interior conditions at the sample houses were adopted for the analysis as indicating actual conditions at the site.

Continuous monitoring of basement air temperature/moisture levels for periods ranging from several days to more than two months was effected using a recording hygrothermograph (Casella London Ltd. Type T9240) in order to overcome any bias which might have been captured in the instantaneous measurements made during a site visit. The continuous temperature and relative humidity traces for the house basement air were adjusted to the sling psychrometer spot results. All adjusted traces thus corresponded to the Environment Canada outdoor measurements.

Concrete wall and floor surface temperatures were recorded on a spot basis using an Amprobe Fastemp thermometer with flat surface probe (19 mm diameter). When held in still air, temperatures indicated with this probe were the same as those indicated with the dry bulb thermometer of the sling psychrometer. When used to determine surface temperatures, thermal contact was improved with the application of a petroleum jelly between the probe and

the surface. Where the concrete was uninsulated and open to the basement air, the back side of the probe was insulated. For insulated surfaces, the probe was inserted between the insulation and the concrete, with minimal disruption to the thermal/moisture regime of the insulated area. The polyethylene vapour retarding membrane was loosened just enough to allow placement of the probe. In only one case was access discouraged by the interior finish (drywall). In the interests of economy and convenience associated with the opening and repairing of the insulated wall and finish, concrete surface temperatures were not obtained for this particular house.

The purpose of the above program of air and wall temperature and moisture measurement was to provide sufficient information to allow comparison of the observed wetting patterns to those which could be predicted by the temperature and moisture conditions in the basements.

4.0 RESULTS AND FINDINGS

4.1 CONTEMPORARY CONSTRUCTION PRACTICES AND THE TYPICAL HOUSE BASEMENT

Construction of single-family dwellings in Winnipeg is today a balanced year round activity with the industry's production dominated by a small number of tract builders. Table 1 illustrates the seasonal distribution of single-family housing starts in the two years prior to September 1987. On average, 29 percent of the permits in this building category were issued in the period December through March, as compared to 40 percent in the four-month period starting in April. Local housing construction activity would thus appear to be little affected by winter climatic conditions.

Virtually all units constructed in the Winnipeg area, summer or winter, are based on a continuous 200 mm cast-in-place reinforced concrete

TABLE 1

SINGLE-FAMILY RESIDENTIAL BUILDING PERMITS ISSUED
FOR
CITY OF WINNIPEG AND ADDITIONAL ZONE 09/85-08/87 (1)

Month	1985/86		1986/87	
	No. of Permits	Pct.	No. of Permits	Pct.
September	262	6.9	317	9.1
October	323	8.6	304	8.7
November	244	6.5	183	5.3
December	178	4.7	125	3.6
January	160	4.2	184	5.3
February	365	9.7	264	7.6
March	359	9.5	485	13.9
April	480	12.7	446	12.8
May	447	11.9	368	10.6
June	326	8.6	225	6.5
July	296	7.9	347	10.0
August	331	8.8	228	6.6
Totals	3703	100.0	3579	100.0

(1) Source: City of Winnipeg Department of Environmental Planning.

foundation wall on a continuous cast-in-place concrete spread footing set between 1.3 and 2.1 m below existing grade on fine-grained lacustrine clays (note: the minimum reinforcement requirement specified for such buildings in Part 9 of the 1981 Manitoba Building Code is three horizontal #20 steel bars set one each at the top [above windows], at mid-height [below windows], and at the bottom of the wall). Interior column supports bear onto concrete pads set at the same elevation. A 75 mm concrete slab which is poured over the top of the footing, pads, and 125 mm minimum of granular fill forms the finished interior floor surface. Main floor joists are cast in to the top of the foundation wall. This typical configuration, conforming to Part 9 of the 1981 Manitoba Building Code, is sketched in Figure 1.

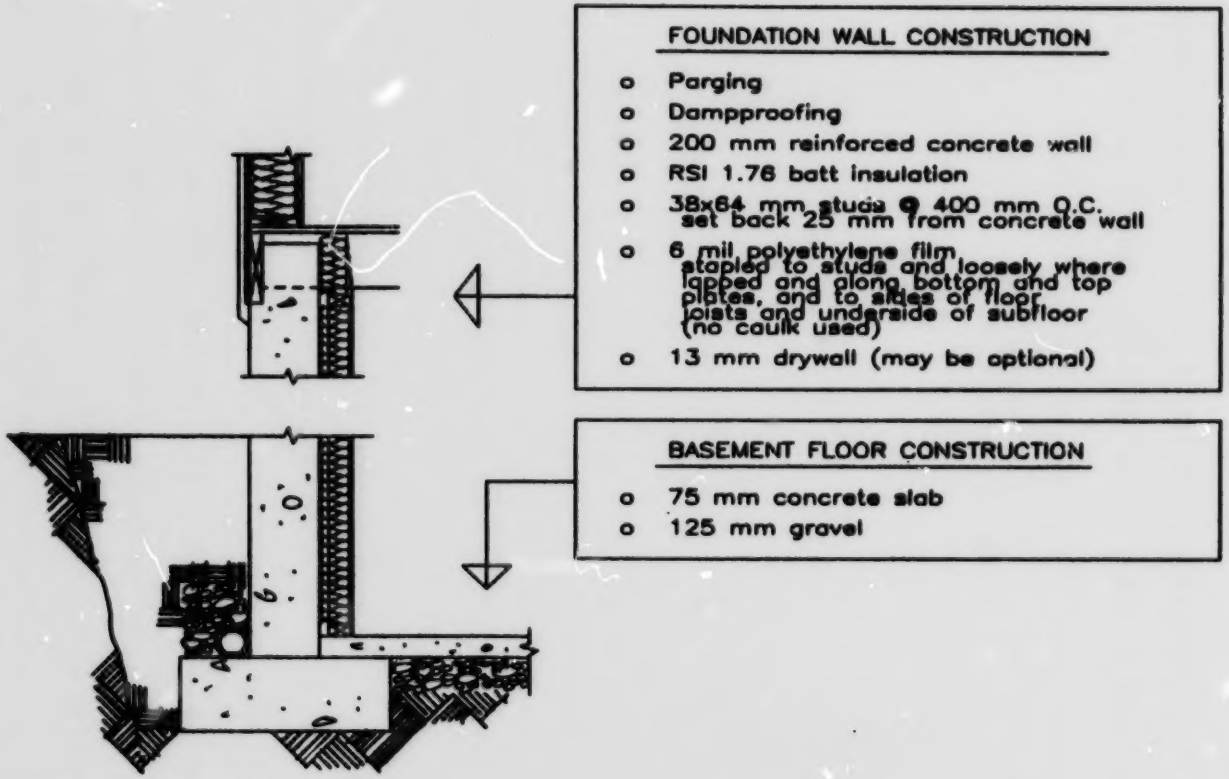

FOUNDATION WALL CONSTRUCTION
o Parging
o Dampproofing
o 200 mm reinforced concrete wall
o RSI 1.76 batt insulation
o 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
o 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)
o 13 mm drywall (may be optional)
BASEMENT FLOOR CONSTRUCTION
o 75 mm concrete slab
o 125 mm gravel

Figure 1. Typical Winnipeg New House Basement Construction

For ready-mixed concrete delivered to the site in winter, heated aggregate is used, and the temperature of the mix as it leaves the plant can be 19 or 20 C. By the time it is placed, the temperature has probably fallen by several degrees. Some effort is made to avoid concrete work in extremely bitter weather, but over the winter the weather does not appear to affect the rate of basement construction significantly.

Heat of cement hydration serves to slow the continued drop in temperature which likely occurs after placement in winter, and straw or batt insulation may be placed over the footing and pads temporarily as a means of reducing the heat loss, but the rate of curing of the concrete can be expected to be significantly slowed by the temperatures encountered. Long-term strength gain may also be affected, but there has not been a noticeable problem with wall or footing damage that could be attributed to lack of strength or durability. While the excavation around the foundation remains open the local subgrade soils are cooled below their normal winter condition.

Once the forms have been removed and foundation and floor joists have been capped with a subfloor (elapsed time: days to weeks), the basement window openings are blocked and the enclosed basement without floor slab is warmed with a portable propane heater. Typical temperatures inside would be 5 to 15 C, but it is not unusual to see frost and ice on the interior side of the concrete wall for some time. Normally this consists of a thin layer over much of the wall to a maximum thickness of one to three centimetres, and sometimes clear ice may be found on the upper part of the wall in the corners. It is a humid environment, as the fresh concrete, propane heater, and the exposed soil are releasing considerable water vapour. In most cases

there has also been an amount of snow accumulated within the foundation perimeter prior to capping. Within about three months or a little longer, there could be people living in the house.

During the framing and finishing stages which follow enclosing of the basement, additional snow may fall on the building prior to its upper envelope being completed. After the floor slab has been installed, but while interior finishing work is continuing, the basement interior may be hosed down several times to clean visible surfaces and enhance marketability. Meanwhile door and window openings are kept closed as much as possible. During the construction period a large amount of water is deposited in the house and given little opportunity to be evacuated.

Summer construction practices are similar except for the requirement to supply heat for the benefit of materials and working conditions. As a result basement windows or the window openings are left open most of the time for ventilation and drying, and the summer sun is regularly present to assist evaporation of moisture delivered within materials or as rain. Generally the construction site is dry and the structure opened to the outdoors during daylight hours.

Dampproofing of the foundation normally is restricted to the exterior of the concrete wall only, where a bituminous coating is used. As the basement floor slab is supported on a granular fill base, Article 9.13.1.4 of the 1981 Manitoba Building Code allows for the omission of dampproofing of the slab, and the practice is uncommon in Winnipeg. Further, Article 9.13.5.3, which deals with interior dampproofing for walls with interior cladding or framing, is interpreted to be applicable (and thus to require interior dampproofing of the concrete wall below grade) only if the wall is providing

support for the interior framing or insulation or finish. Local practice has the interior framing fastened both to the floor slab and to the joist system above, offset from the concrete wall, and this framing supports the batt-type insulation as in Figure 1, so interior dampproofing is rarely applied.

In the limited number of cases in which interior damproofing is applied, polyethylene sheeting typically is fastened in place between the insulation and the concrete wall surface from the level of the outside grade down to the floor slab. Building paper has also been used for this purpose.

By Subsection 9.26.6 (1981 Manitoba Amendment to 1980 National Building Code), the upper part of foundation walls enclosing heated space must be insulated from the underside of the subfloor to not less than 600 mm below the finished grade. For foundation walls less than 50 percent exposed above grade, which is the case for almost all units constructed in Winnipeg currently, the 1981 Manitoba Building Code requires a minimum of RSI 1.6 thermal resistance (Article 9.26.6.6). It is common practice to frame and insulate the wall over the full height, however, and typically RSI 1.76 or RSI 2.11 glass fibre batts are used.

Vapour barriers are required by Subsection 9.26.5 for the warm side of insulation, to prevent condensation problems and protect the entire wall surface. The materials in common use for this purpose provide high resistance to vapour passage directly through the materials. However, the 1981 Manitoba Building Code provides only loose assurance of continuity in the vapour barrier, requiring, for example, in 9.26.5.7, continuity around openings such as electrical boxes, registers, fans, etc., but in 9.26.5.6, minimum overlapping distances applicable at joints.

In practice there are very few vertical joints in the 6 mil polyethylene commonly installed around the basement perimeter, because it is convenient to make use of wide continuous rolls of the material, but resistance to vapour transport by air movement is poor at the bottom and top of the frame wall where stapling is used as the method of attachment. Often the bottom of the polyethylene membrane fails to extend as far down as the bottom plate of the wall. At the top, the polyethylene is cut roughly to fit up around the floor joists and is stapled loosely to the sides of the joists and to the underside of the subfloor, thereby holding a suitably sized piece of glass fibre batt in place against the concrete. It is common to find several of the joist spaces in a house lacking the presence of the polyethylene entirely, or merely lacking the staples to hold it in place.

Caulk or other sealing mechanisms are rarely employed to establish vapour barrier continuity in conventional house basements in Winnipeg.

At the present time, the polyethylene film installed over the basement wall framing is considered to provide sufficient mechanical protection for the insulation system, so it is common for the builder to provide further finishing only as a sales option. Once the wall is sheathed to within 300 mm of the floor, it is designated as "finished" and subject to servicing according to the Manitoba Electrical Code.

The foundation/insulation system shown in Figure 1, with or without a drywall finish, represents the typical Winnipeg new home basement. It has evolved as a response to a combination of local market preferences, the currently applicable building code requirements, discussed above, and other factors. A new Manitoba Building Code, based on the 1985 National Building Code with amendments made by the Manitoba Building Standards Board, is

expected shortly. Some of the Articles relevant to dampproofing, insulation of basements, and measures to prevent condensation will change somewhat in the new Code from those which have helped shape current building practices in the Province. These changes may have some effect on the causes and on the occurrence of basement condensation problems of the type examined in this report, but it would appear from the findings of this project that the mechanisms of the phenomenon are basic and the implications for future building practices are fairly clear.

4.2 THE BASEMENT CONDENSATION PHENOMENON

When interior concrete surface temperatures are low enough, and the moisture content is high enough in interior air allowed to reach the immediate vicinity of the concrete surface, condensation of water vapour can occur. Generally, the degree of saturation of air rises as it is locally cooled by proximity to a cooler object. In other words, the ability of the air to hold water vapour decreases as the air is cooled. At some temperature the air becomes saturated (100 percent relative humidity). Further cooling results in a further decrease in capacity to hold moisture, and the excess is removed from the air in the form of liquid water. The air directly contacting the object which is effecting the cooling is locally the coldest air, and it is the excess moisture in this air which is removed. The removed moisture accumulates as liquid water on the surface of the adjacent object.

Condensation will proceed as long as the supply of moisture-laden air and the temperature of the air-cooling object are maintained, and contact between the two is allowed. If the amount of water production is significant due to high indoor humidity, low object temperature, good

communication, or some combination thereof, the water may run down and pool at the base of the object. A familiar example of this phenomenon is the interaction which may occur on the interior side of a window during cold weather.

In Canadian basements, conditions are often right for condensation and the occupants of many homes coexist with a recurring condensation problem. Construction of houses with improved airtightness characteristics has become increasingly common in recent years, resulting in more homes with elevated interior humidity levels, particularly in winter when dissipation of excess moisture to the outdoors is discouraged by the desire to keep heat in and cold drafts out.

Concrete foundation walls are exposed to the adjacent, cool soil, and particularly to ambient outdoor air temperatures, and in consequence provide a cool surface in the interior of a house. The interior surface temperature may be even further depressed by the presence of thermal insulation on the interior side of the wall, between it and the interior air. If the air is allowed into the vicinity of the concrete, and the concrete temperature is low enough (below the saturation or dewpoint temperature for that air), then visible condensation may occur. If wall temperatures are below zero, then this condensation will be present as frost and ice.

Uninsulated concrete walls in partially or fully heated Canadian prairie basements are normally unaffected by this problem because the dewpoint temperature for the relatively dry winter air is exceeded over the entire surface of the concrete. However, it is common to find ice build-up on the near-grade and above-grade interior parts of the foundation wall when the wall has been insulated on the interior side but adequate retardation of

vapour and air movement to the wall has not been provided. A portion of the Manitoba houses built since the 1950's, with basements insulated at the time of construction or some time later, have exhibited this phenomenon. Some concern and damage has been reported by occupants when the ice has melted suddenly with the onset of warmer weather.

In summer, mechanical systems such as space heating appliances and local exhaust fans which serve to circulate, mix, and replace the interior air of a house, are typically not operated. Thermal stratification of the more stagnant house air results in basement air temperatures below the overall average in the house. The basement environment is influenced strongly at this time by the temperature of the soil or rock on which the house is founded, the concrete walls not being heated intentionally from the interior.

Ambient air moisture levels outdoors and indoors are significantly higher in summer than in winter. If the foundation drainage system and dampproofing are not functioning efficiently at the same time, the continuous or intermittent presence of water below grade may also contribute to higher moisture levels in the interior basement air. Basement condensation in summer (i.e., more generally, in the non-heating season) will result from the right combination of the above factors. Its occurrence in Canadian homes is probably more widespread than the icing of walls in winter which is described above. Dampness, musty odours, and proliferation of insects and fungal growths are the objectionable by-products.

4.3 NEW HOME BASEMENT CONDENSATION IN WINNIPEG

Of the nine cases of new-home basement condensation problems examined in this project, all were identified for the study because of homeowner

concerns, and all were subjected to efforts to alleviate the problem during part of the monitoring period. Consequently it was possible to observe, at least partially, the phenomenon's dynamics. In some cases, observations were made of the basement in its as-delivered condition, but with condensation symptoms present. In others, efforts to combat the problem had been ongoing for some time before the first site visit. The persistence of the problem and the rate at which it can be cleared up varies among houses.

From the site visits and the reports of homeowners, builders, and building officials, an impression of the presence of the condensation in a typical case has been assembled and is sketched, from a bird's-eye perspective, in Figure 2. Observations of wetted areas in the sample houses are included in Appendix A.

Prior to any remedial efforts, the full-depth wall insulation, vapour retarding membrane, and a drywall finish (in some cases) are in place as when the house was first occupied. The bottom of the finished or unfinished wall is wet, with free water standing under and beside the bottom plate of the wall framing. In low spots on the floor, pools of water are present, and there may be wet lines of flow from the perimeter to the pools, between pools, and leading to the floor drain. The insulated wall looks normal otherwise, but the basement feels damp, cool, and possibly may be emitting a musty odour.

When the wall is opened up by removing finish (if any), polyethylene, and batt insulation, the condition shown in Figure 2(a) is typically found. There is a considerable volume of free water trapped and standing between the bottom plate and the concrete wall and the wall itself is wet. The bottom row of batt insulation (typically 380x1220 mm batts) is wet on the

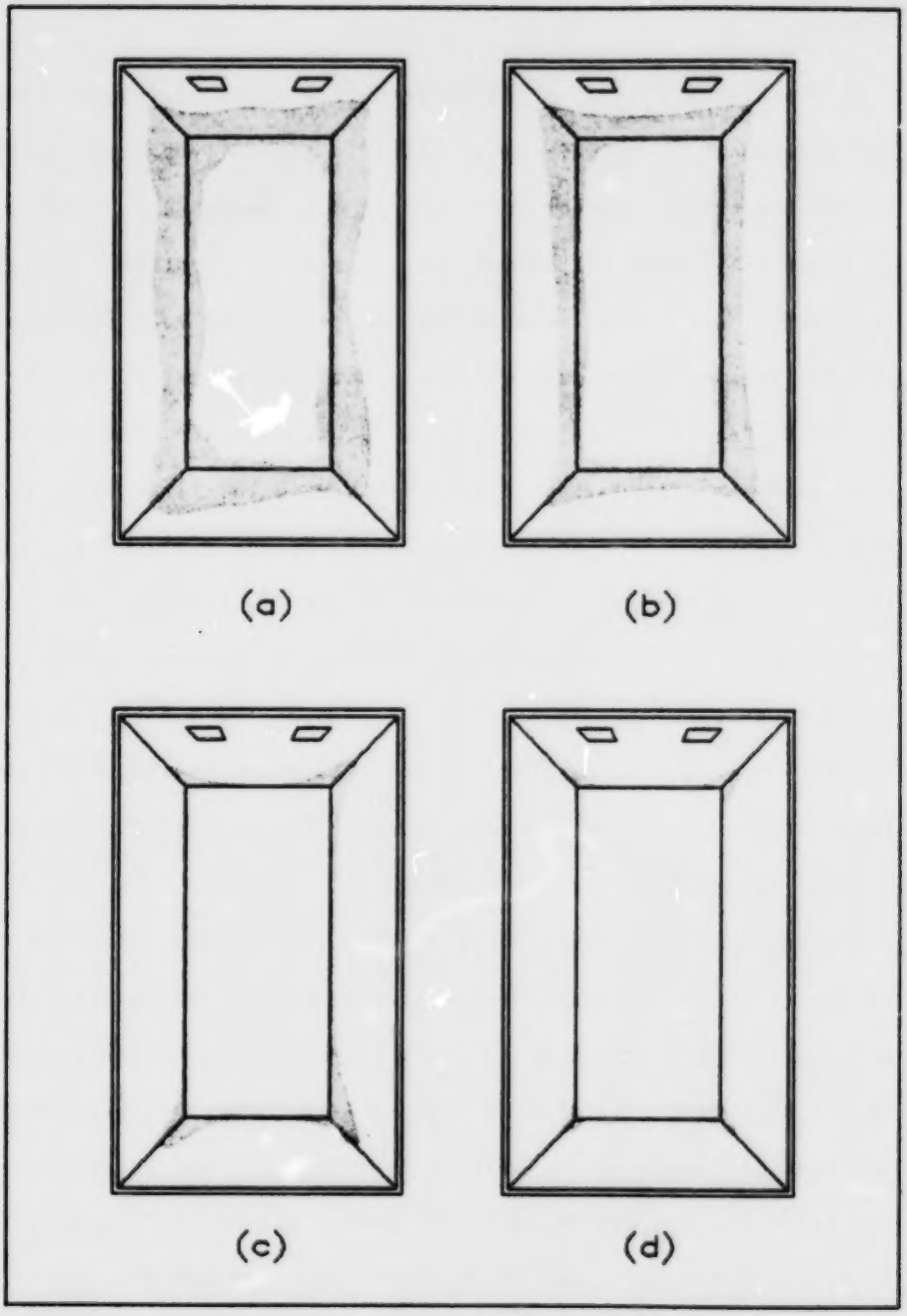


Figure 2. Basement Condensation in Winnipeg New Houses: Wetted Surfaces
(a) Just after exposure of concrete by removal of insulation and polyethylene,
(b) Several hours after exposure of concrete,
(c) After several days to several weeks of exposure,
(d) After several weeks to several months of exposure.

concrete side and damp on the polyethylene side, having absorbed some condensation. The upper row of batts is generally dry but is often damp toward the bottom, except for those in outside corners, which may be as wet as those taken from the bottom row. The wetting pattern on the wall is irregular, having been affected by the contact or lack of contact between the surfaces of individual batts and the concrete.

After several hours of exposure to basement air, the wetting pattern may look somewhat like that in Figure 2(b), with the floor pools remaining, but with the wet/dry line on the wall having become distinct and regular along the length of the wall. The extent of the wet surface above the floor is minimum at mid-wall (or at inside corners, if present), and is maximum in the outside corners. This pattern resembles the expected distribution of lines of constant temperature around a basement perimeter, with higher temperatures above, lower temperatures below, and lowest temperatures at the base of the wall and in the corners.

Several days to several weeks later, during and after the application of varous measures including ventilating by running circulation fans, opening windows in the basement and elsewhere in the house, warming the space, and operating a dehumidifier, the area of wetted concrete has decreased to that typified in Figure 2(c). Batt insulation which was stacked in the basement for temporary storage is no longer damp. Mid-walls have dried almost to the floor but there still may be standing water between the bottom plate of the framed wall and the concrete wall, and the bottom plate remains wet around most of the perimeter. The corners can still be wet up to more than 1.2 m above the floor. All previous pools of water located more than 150 mm from the perimeter frame wall have disappeared.

During the time between opening of the wall and reaching the condition shown in Figure 2(c), it is noted that the presence of water at the base of the wall appears to increase following a major precipitation event, which in Winnipeg in summer is usually infrequent and comprises a day or so of wet weather interspersed with several thundershowers. The increase in pooled water does not appear to be associated with single thunderstorm events during periods of hot weather. Examination of project basements after rain events showed that leakage via form-tie penetrations or any other means was non-existent or, at worst, very minor. It is usual for the builder to return to patch leaks once they have been definitively located. There were no visible cracks in the concrete walls of any of the new houses in the group. It is concluded that the rate of condensation in the still-damp basements may increase following wet weather due to temporarily elevated humidity levels.

After several weeks to months of exposure to the air in the basement, only the corners remain distinctly wet, as sketched in Figure 2(d). The wet/dry line may extend one or more stud spaces on either side of the corner, and may reach more than 0.5 m above the floor. Bottom plates can still be wet in the corners, but around most of the perimeter they have dried to the touch.

In some houses the lower corners particularly may remain damp for significantly longer than months, and may stay that way for some time if the insulation and polyethylene are replaced. However, in most cases the problem does not recur to a severity which alarms the occupants (i.e., builder or other authorities are not alerted) if the wall has been restored after one or two months of exposure and has appeared to be dry at that time.

An exception to the above is House # 1 of the project sample which was built in early 1984 and has had incidences of winter and summer condensation several times, the latest being in late winter 1987. When exposed, the walls dry within approximately one week. Recurrence in this case may be attributable to a poor air/vapour barrier which is the result of repeated removals and replacements. Several other houses which were built since 1984, and which have experienced similar recurring or ongoing condensation problems, were encountered during the course of the project. Houses # 2 and # 4 are examples.

4.4 BASEMENT CONDENSATION MECHANISMS IN THE STUDY HOUSES

Measurement of wall temperatures and moisture content of house air in the fourteen houses examined during the project was sufficient to provide general insight into the nature of the condensation problem occurring in new home basements in Winnipeg, although a larger sample would have been advantageous in clarifying some of the inconsistencies and questions which arose with the first group of fourteen. The findings are summarized in Figures 3 and 4. Details on individual houses are included in Appendix A.

4.4.1 Wall Temperatures

An interior surface temperature profile was prepared for part of the perimeter of House # 10 and spot observations were made over the height of the wall at from two to six locations in each of twelve other houses. The seasonal effect of outdoor air and soil temperatures is evident in the wall temperature observations which were made at various times in different houses in the three month interval between late May and late August 1987. There was a gradual warming of the soil adjacent to the foundations over the interval and, as a result, the wall temperatures cannot be compared

numerically among all houses. Valuable insight may have been generated from an investigation of the soil temperature distribution in space and over the spring and summer around one or two of the typical foundations in the study sample. However, sufficient continuity in the timing of the interior observations was obtained to allow an adequate appreciation to be provided about wall temperature regimes in Winnipeg and their relation to the condensation phenomenon.

The presence of interior insulation of the level of thermal resistance typically installed in the houses (slightly in excess of the RSI 1.6 specified in the applicable building code [Section 4.1, above]) serves to depress concrete wall interior surface temperatures by 2 or 3 degrees Celsius below the values typically found during summer at similarly located points on an uninsulated wall, or a wall from which the insulation has been removed for about two weeks or more. The surface temperatures near and above grade on such exposed walls generally change with short-term variations in average outdoor temperatures, but at a depth of one metre from grade the temperatures gradually rise from levels near 12 or 13 C in late May to values near 15 to 18 C by late August.

For deeper basements, concrete wall surface temperatures two metres below grade gradually rise from approximately 10 or 11 C to about 15 C over the same interval. Interior air temperatures maintained in the project sample basements over this period were in the range 17 to 22 C, the higher values being reached after several days of well-above-normal outdoor temperatures and the lower ones being recorded in the early part of the day in basements with windows open for ventilation. For Winnipeg, these are typical seasonal values for most houses.

Temperatures on the floor slab itself increase quickly toward the centre of the floor and, for project houses, were really only in the same range as below-grade wall temperatures for a distance of less than one metre from the base of the wall.

The residual effect of excavation of soil to place the foundation and the subsequent exposure of sub-grade soils to low temperatures during winter construction would appear to be insignificant with respect to the basement condensation problem. Wall temperatures measured in 30-year-old houses # 10 and # 11, as well as in other project houses built more recently but before 1987, are similar to those encountered in the most recent homes soon after the insulation has been removed. In the short term, however, the presence of insulation installed in winter or early spring may inhibit the one-time recovery of ground temperature near the foundation if artificially low values were induced during the construction interval. The effect of this could be to accentuate the condensation problem at the beginning of occupancy.

Houses # 13 and # 14, with insulation on the exterior of the concrete, exhibited much smaller temperature variation than did the other houses over the full height of the wall, i.e., in late August the change in temperature from floor slab to floor joists was slightly greater than 1.5 degrees Celsius. Wall temperatures ranged from one to three degrees below the basement dry bulb temperatures maintained in the two houses, but were above the dewpoint temperatures for the basement air.

4.4.2 Air Moisture Content

Prairie air moisture levels outdoors follow a seasonal pattern which peaks in the summer. There are significant short-term deviations from the

month-to-month level which are attributable to passing weather systems. For May through August, the 1987 pattern of outdoor air moisture content in Winnipeg is included in Figure 3. The measure of moisture content used, humidity ratio (also known as specific humidity), expressed in units of mass of water in vapour form compared to the mass of dry air in the same volume of air, is calculated on the basis of dry bulb temperature of the air and either wet bulb temperature or relative humidity, depending on the instrument used. Atmospheric pressure variations are ignored for convenience in the calculation, as their impact on calculated humidity ratio and dewpoint temperature is less than the degree of accuracy obtainable in field studies of this nature.

Indoors, the air follows the outdoor seasonal pattern, with variations imparted by the restriction in air flow between indoors and outdoors which the building envelope provides, by the use of doors, windows, and mechanical systems which aid in the air exchange process, by the rate of internal generation of moisture, and by moisture storage in and release from building materials. The resulting indoor pattern, for typical occupancy in houses not recently constructed, is illustrated in Figure 3 for houses # 1 and 11.

Short-term outdoor changes are not felt indoors, and even the more gradual seasonal changes are responded to only slowly. It would appear from the figure that early spring indoor moisture levels in house # 1 still reflect a moist winter indoor environment as late as the end of May. Basement humidity in House # 11 (windows predominantly closed, no forced ventilation) through the latter part of August is clearly lagging behind the late summer drop in outdoor moisture content. These results show that the seasonal effect of moisture storage in a home can be significant.

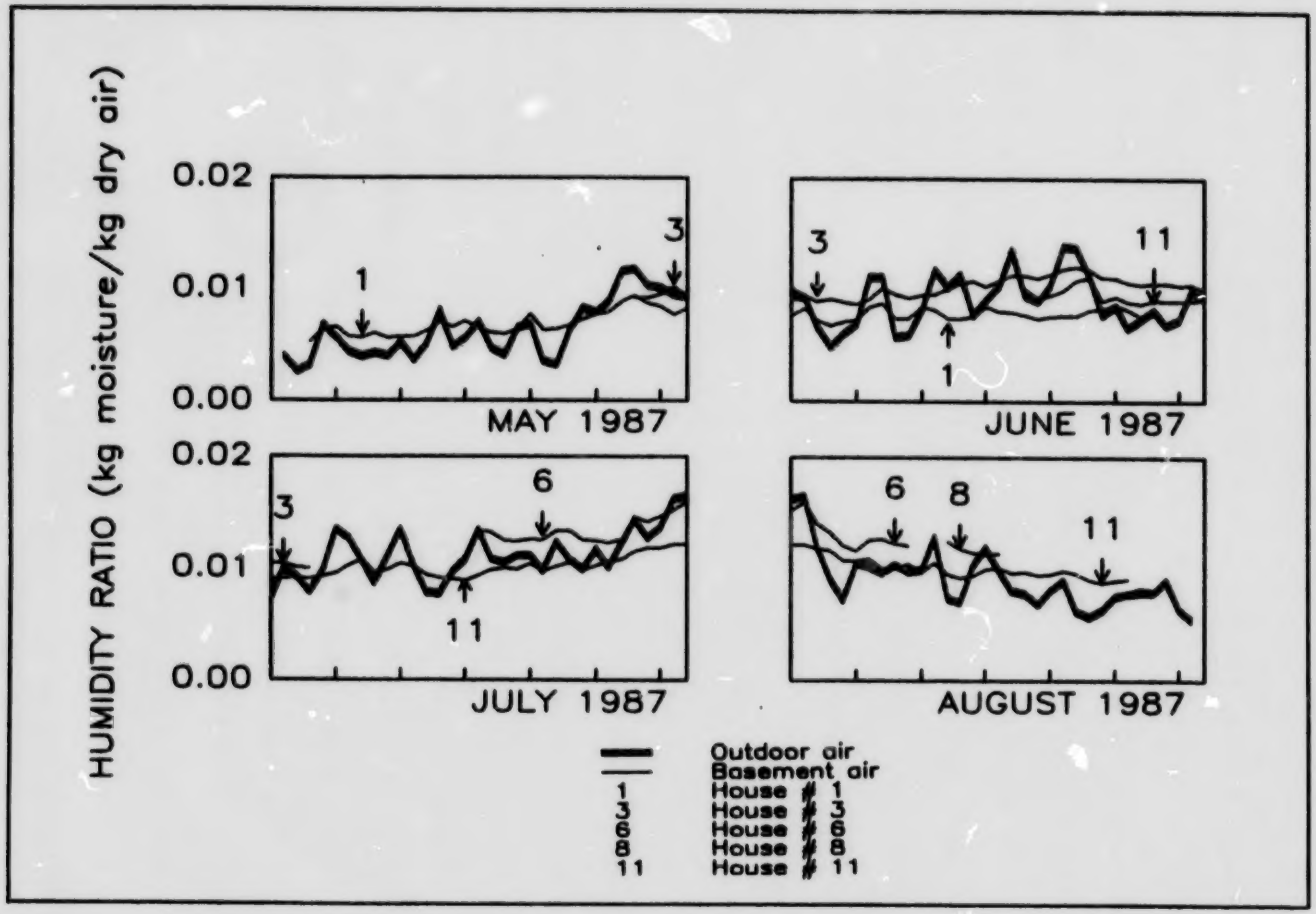


Figure 3. Moisture Content of Winnipeg Outdoor Air and Basement Air of Selected Project Houses

The greater the rate of air exchange with outdoors, the more closely the trace of indoor air moisture content matches the outdoor trace. Houses # 13 and # 14, each with continuous mechanical exhaust and replacement by inflow across the envelope, are operated in summer very close to ambient outdoor moisture content.

The wettest basements encountered in the project sample, those of houses # 3, # 6, and # 8, are compared to outdoors and to older basements in Figure 3. During the period of monitoring in these units, pools of water on the floor were evaporating and disappearing, and stacks of wet and damp glass fibre batt insulation were drying in the basements. There was some effort to dehumidify in # 3, and forced circulation of air along with open windows was being applied in # 6. In # 8, the dehumidifier was not operating and windows were closed. The incremental air moisture level in these basements beyond average ambient outdoor values was approximately 0.001 to 0.003 kg of water per kg of dry air, or about 0.6 to 1.8 kg of water in a typical house volume of 500 cubic metres with a typical summer outdoor condition of 0.01 kg moisture per kg of dry air. Peak outdoor moisture contents regularly exceeded the values recorded in these wet basements for several days in succession.

With the exception of the above, other project houses which did have significant wall condensation also had air moisture content levels which were not greatly different, over a period of weeks, from the average outdoor values. The fact that dehumidifiers were operating in some of them, and that, in some, the initial remedial drying period of wet stacks of insulation and standing water was completed prior to or shortly after the beginning of monitoring, probably contributed to the lower humidities.

It should be noted that, in all project houses, the moisture content of air in rooms on upper levels was effectively the same as in the basement; this can be explained by the relative ease with which air can circulate and mix throughout the interior of a house compared with the restriction to flow which is normally provided by the building's outer envelope.

4.4.3 Relation Between Air Moisture Levels and Observed Wall Condensation

Air in a typical basement in summertime, maintained at 19 degrees Celsius with a humidity ratio of 0.01 kg moisture per kg of dry air, has a relative humidity of approximately 72 percent, and a dewpoint temperature of about 14 C. The latter is just about the same as the temperatures that would be found near the base of the concrete wall in the typical house as reported above. An increment in moisture content of about 10 to 30 percent (i.e., 0.001 to 0.003 kg water vapour per kg of dry air) would raise the relative humidity in the basement to between 79 and 93 percent, and the dewpoint of the air to between 15.5 and 18 C. These are well within the range of temperatures found on both wet and dry concrete walls in various project houses, particularly prior to removal of insulation.

Late in the spring, the relative humidity and dewpoint temperature in the air of the 19 degree basement at a typical humidity ratio of 0.007 would be approximately 51 percent and 8.5 degrees, again close to the range of temperatures measured lower down on the walls in project houses. A similarly elevated moisture content as in the above example would raise the dewpoint of the basement air to between 10.5 and 14 degrees. It would appear from this investigation that many conventional houses must have some interior concrete surfaces which are, at least for part of the year, at a temperature close to or less than the dewpoint of the basement air.

Figure 4 is a summary of the wall/air moisture level findings for the project houses. Figure 4(a) represents the typical condition of a basement which has been exposed to basement air for some time. Part of the wall surface may be below the dewpoint temperature for the air in the basement, but the visibly wet surfaces cover a much smaller area, and these are usually only in the corners. In some cases, part of the wall may be below the air's dewpoint without there being any visible wetness. In some cases, there may be no surfaces which are cooler than the dewpoint temperature.

Figure 4(b) represents an undisturbed basement, i.e., the insulation and polyethylene are still in place. The wetted surface extends up the wall only just as far as, or less than, the level which would be indicated by the calculated dewpoint based on basement air. In the corners, which are the wettest surfaces, the difference is greatest between the actual wet/dry front and the position suggested by the dewpoint of basement air. The two almost coincide at mid-wall, where typically the wall surface is wetted but there is little free water. The discrepancy indicates that the air in the wall cavities is somewhat drier than the basement air, a phenomenon which would occur when there was ongoing condensation at the wall surface, along with air circulation within the cavities, but with somewhat restricted access to entry of basement air.

Figure 4(c) represents a basement within approximately the first month of exposure to basement air following removal of the insulation and polyethylene. The estimated and actual locations of the wet/dry line or dewpoint position coincide fairly well.

In the case of Figure 4(a), there may be some local drying of air in the boundary area next to the wall which is caused by local condensation and

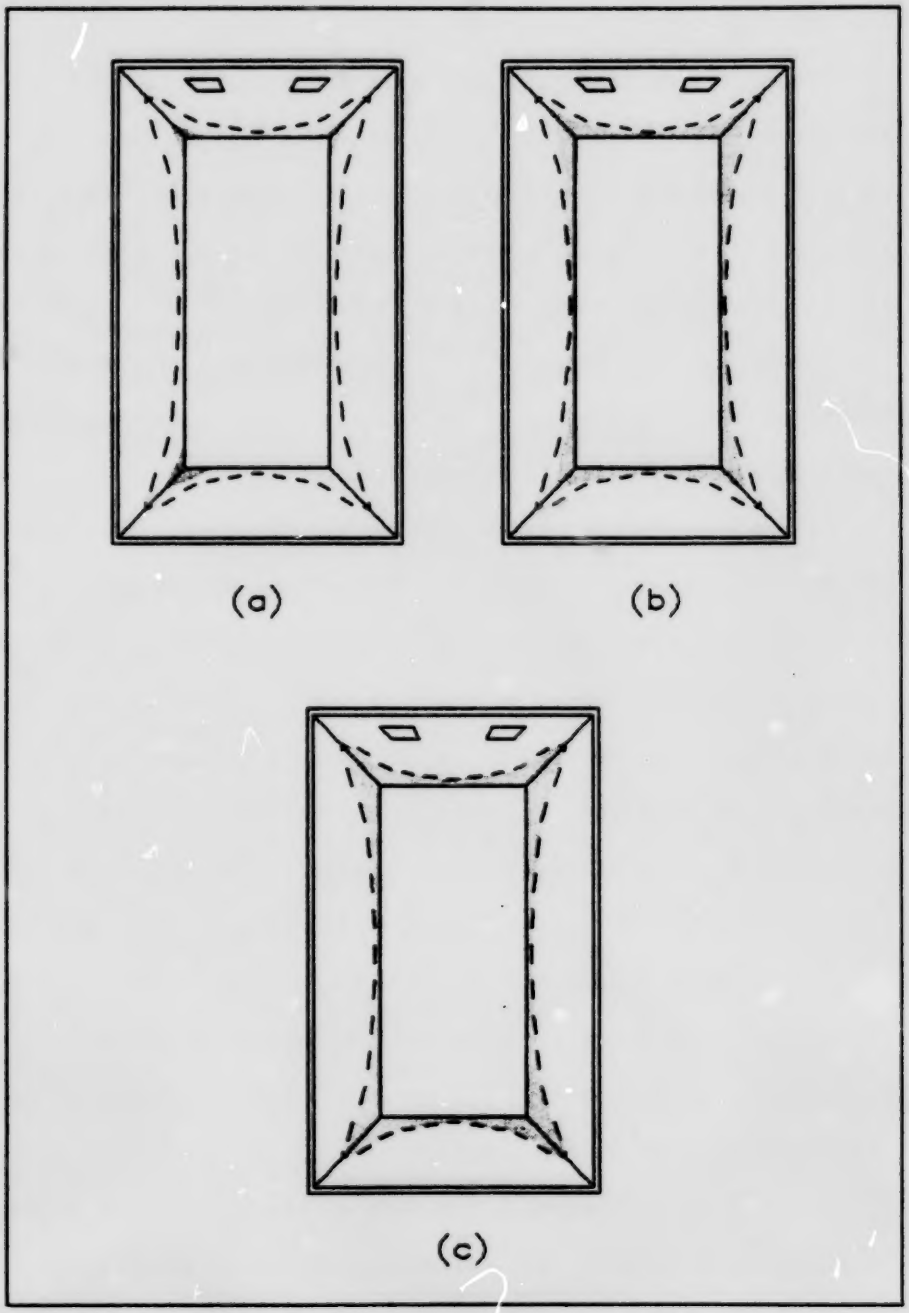


Figure 4. Relation Between Wall Temperatures, Basement Air, and Wetted Surfaces (broken line represents wall temperature equal to dewpoint temperature of basement air):
(a) Older homes and newer homes with concrete exposed for minimum of weeks to months,
(b) Undisturbed new home prior to exposure of concrete,
(c) New home where concrete has been exposed for several days to several weeks.

near-wall air circulation, but this effect is not likely fully responsible for the lack of wetted surface where one is predicted from the presence of low wall temperatures. More likely is the fact that the concrete itself has, over time, lost some of its non-bound water and dried out to the point that its surface is no longer saturated and the non-saturated zone may extend several millimetres below the surface.

Normally it will take months to years for concrete slabs which are continuously exposed to drying environments (e.g., typical room temperatures and approximately 50 percent relative humidity) to begin to dry at a depth of several centimetres. The rate of drying of the concrete can be accelerated considerably by the application of heat. Concretes with higher permeability, e.g., leaner mixtures with lower cement content, also dry faster.

It may be expected that the non-saturated concrete wall has some hygroscopic capacity to absorb seasonal excesses of interior moisture, just as do other materials such as wood. This is an important property for the short-term avoidance of condensation in the large proportion of house basements which would seem to be operating at very close to condensation-producing conditions for at least part of the year. This may be the most important implication of the observations made during the project, i.e., that the problem is a new home problem because the concrete foundation is still almost saturated with unbound water and lacks capacity to absorb moisture from the air.

The basement walls depicted in Figure 4(c) have not, until recently, been exposed to good drying conditions, as the insulation and polyethylene have been continuously in place since the time of construction, which was

probably during colder weather. Their environment was a cool, humid one between the time they were placed and the time they were semi-isolated from the interior air. Once exposed, they warm up rapidly, and the predicted and actual locations for the wet/dry interface begin to closely coincide. The wetted area does not increase noticeably; rather, the line of equal temperature on the wall corresponding to the dewpoint of basement air drops quickly as the wall warms. It would appear from the coincidence of the two lines, compared to the observation in older basements, e.g., Figure 4(a), that the concrete is still virtually saturated. In time the basements of Figure 4(c) begin to look like those in Figure 4(a).

When it rains and the air of Figure 4(c)-type basements has responded with its own slower and temporary increase in moisture content, it is reasonable to expect the increase in condensation which has been observed by some occupants, because of the accompanying short-term increase in dew point temperature. For a short time, more of the exposed wall can act as a surface for condensation.

House # 9, with excavation at the end of May 1987 and with end of August occupancy, was dry except for one corner when it was examined in mid-August with insulation and polyethylene in place. Over the lower wall the temperatures were low enough to be below the dewpoint of basement air at least part of the time. No enquiries were received concerning wet basements in Winnipeg houses first occupied in the summer of 1987.

Finally, it should be noted that the new home basement condensation problem has not appeared to any extent in either Saskatchewan or Alberta, according to Warranty Program officials in those provinces. In Alberta, new home basement insulation is normally installed to the local building code-

specified depth of 600 mm below grade only, while in Saskatchewan, basement insulation is not required, and is rarely provided in a new home unless by special agreement.

5.0 CONCLUSIONS

Comparison of the field observations and monitoring data from the fourteen project houses with the reports of builders, building officials, and homeowners has provided the following insights into the condensation problem in new home basements in Winnipeg:

(1) Houses constructed according to conventional building practices entirely during cold weather, with insulation applied over the full height of the concrete foundation wall next to its interior face, are prone to exhibiting subsequent condensation and pooling of water on and at the base of the wall, particularly in the first summer of occupancy.

(2) The houses with summer basement condensation have concrete wall surface temperatures about the same as older and drier conventional basements, with and without interior insulation, and such temperatures are close to the dewpoint temperatures for the air in houses in summer.

(3) The moisture content of air in the basements in summer varies much less rapidly than does that of outdoor air, but average levels are the same as or slightly higher than seasonal outdoor levels. In the wettest basements monitored during the project, average indoor air moisture levels in the presence of standing water and wet insulation were higher than average outdoor levels by approximately 0.001 to 0.003 kg of moisture per kg of dry air, or about 10 to 30 percent higher than typical summer values. After the initial drying period, or with minor efforts to ventilate or dehumidify, air moisture contents in basements with condensation were similar to those of older houses or of outdoor air.

(4) After exposure of the concrete wall to free basement air for a period of several weeks to months in the summer, by temporarily removing the insulation and polyethylene membrane, the wall and floor become visibly dry and the problem usually does not recur to any significant extent after insulation and polyethylene are replaced.

(5) An imperfect air/vapour barrier results from the conventional building practice of applying a low-permeance polyethylene membrane to the interior surface of a framed and insulated wall next to the concrete wall and fastening it in place with staples. Vapour protection is poor because the air/vapour barrier is discontinuous next to the floor slab and in the joist/header spaces. Interior air can get past the barrier and circulate to the cold side of the insulation. There is evidence that movement of moist basement air into the wall cavities and behind the insulation is partially restricted by the current practice of stapling the polyethylene, but the relative contributions to the condensation problem by the moisture in basement air and by the moisture available from the fresh concrete were not determined in the project.

(6) Older basements appear to have a less severe, non-recurring, or non-existent problem while having more or less the same imperfect air/vapour barrier, basement air moisture levels, and wall surface temperatures, but their concrete may have been subjected to unaided drying conditions over time, or to accelerated drying. This is an indication that the fresh, saturated concrete of a new home has little or no capacity to absorb and store seasonal or other short-term excesses of moisture present in the air.

6.0 RECOMMENDATIONS

6.1 REMEDIAL MEASURES

For new house basements in which condensation has occurred, resulting in wet insulation and framing next to the concrete wall, or where it is continuing to occur, it is recommended that the framed wall be opened up to expose the concrete, and that good drying conditions be provided in the basement for at least one month and preferably for several months before the interior framed wall is restored. A favourable drying environment would include a temperature in the range of normal room temperatures, i.e., 18 degrees or more (the higher the better), and air moisture levels equal to or less than normal seasonal values.

In summer the desired reduction in basement air moisture levels can be provided easily by opening windows in the basement and upper levels of the house and encouraging natural exchange of air with outdoors. The

application of forced ventilation would be beneficial but probably would not make much additional difference. Similarly, air exchange via windows is probably more effective in reducing interior moisture contents than a dehumidifier would be. Humidity ratios in project house basements were only slightly above outdoor values, and the opening of windows appeared to almost eliminate the difference.

If the remedial drying is to be done during winter, the necessary interior temperatures would be provided by normal heating of the house. The dryness of the interior air available to accept moisture released from the concrete would vary from house to house depending on lifestyle, and, in some cases, this air may give up moisture to the concrete, thus counteracting remedial efforts.

Unless the problem is allowed to go on for years before being treated, the glass fibre batt insulation and wood framing materials, when dried, will not have been adversely affected in function by the condensation. With the wet materials there is, however, a potential for wood rot and for growths of moulds and mildew. Once established in the basement, the latter may persist long after the wood has dried, with consequent potential allergenic and health effects, so it is desirable to eliminate the presence of moisture as soon as possible.

When the interior wall is returned to a completed condition following a sufficiently long period of exposure of the concrete, it is an opportunity to effect a properly sealed barrier to moisture transport via air flow from the interior air space to the wall cavities and concrete surface, in order to provide an additional measure of security that the condensation problem or ice build-up will not recur.

6.2 CONSTRUCTION PRACTICES

Prairie manufacturing of housing in winter using cast-in-place concrete foundations is not new. Ways of coping with the elements have evolved to the point that, as evidenced by indicators of construction activity, the rate of production of houses is now scarcely affected by winter. The recent practice of insulating the foundation on the interior for the full depth appears to have inhibited the normal process of removal of excess moisture from the concrete, and significantly so if the construction takes place during cold weather. This phenomenon could become more widespread as and if full depth insulation became more common across the country.

For the most part it is unrealistic to attempt to change construction practices radically in order to deal with a problem such as basement condensation. The authors therefore consider that it would be inappropriate to advocate, as a remedy, a switch away from cast-in-place construction to pre-cast or pressure-treated wood foundations or the provision of a suitable drying environment for fresh concrete through complete hoarding, heating, and moisture removal. Rather, simple changes would be more reasonable, and early acceptance would be more likely. It should be noted that the following are untried suggestions, the implementation of some of which may not be straightforward:

(1) The concrete wall, if it is to be insulated on the interior, should be left open for some time after construction (e.g., as much as one year) before completing the interior finish. It could be framed at the time of construction. The way in which building codes are applied to new home construction would have to be adjusted to allow for this.

(2) Exterior insulation of foundations, already a familiar but not dominant practice, leaves the fresh concrete exposed to interior air and provides thermal resistance in a location which meets current code requirements and also keeps the concrete warmer.

(3) Every effort should be made to keep interior humidity levels in the building shell as low as possible during construction in winter by restricting the use of water and the bringing in of damp materials. The use of portable heaters which do not produce the quantities of water vapour generated by the current propane-fired units should also be considered.

(4) Installation of a properly sealed air/vapour barrier in the basement may contribute to reduced concrete condensation problems, particularly in houses where the occupants generate considerable winter moisture. Although far fewer houses are built to R-2000 standards than to conventional standards, there has not been a noticeable incidence of basement condensation in the former. Attention to the establishment of air/vapour barrier continuity during construction of R-2000 houses is, by intent, very high. It is noted, however, that winter interior moisture levels in R-2000 houses are probably lower than in typical conventional homes built to meet current codes, because of the continuous ventilation systems characteristic of the former group. In fact, the dryness of interior air has been a common complaint of R-2000 homeowners.

(5) The rate and significance of air circulating from the basement space to the cavities via passages around, rather than through, the polyethylene membrane was not ascertained during the project (this would be difficult to do), but, if an effort to provide a well-sealed air/vapour barrier is not practicable in the current market, then inhibition of this circulation through provision of a barrier to air flow somewhere along the flow path may be a reasonable approach. For example, as sketched in Figure 5, a wider top plate could be used to bridge the gap between the framing and the concrete wall without significantly complicating the construction or increasing its cost.

(6) Given that temperatures behind insulation and next to the concrete wall are likely to be at or below the dewpoint for basement air for at least part of the year, and that current installation practices for vapour protection do not provide a completely sealed barrier to vapour transport via air flow, it can be expected that any polyethylene or other low permeance material placed between the insulation and the concrete wall as a protective barrier to moisture from outside will be subject to condensation formation on both sides. None of the project houses had such interior moisture protection, however, so the phenomenon was not observed to occur, and only anecdotal reports of the problem were received from builders and officials.

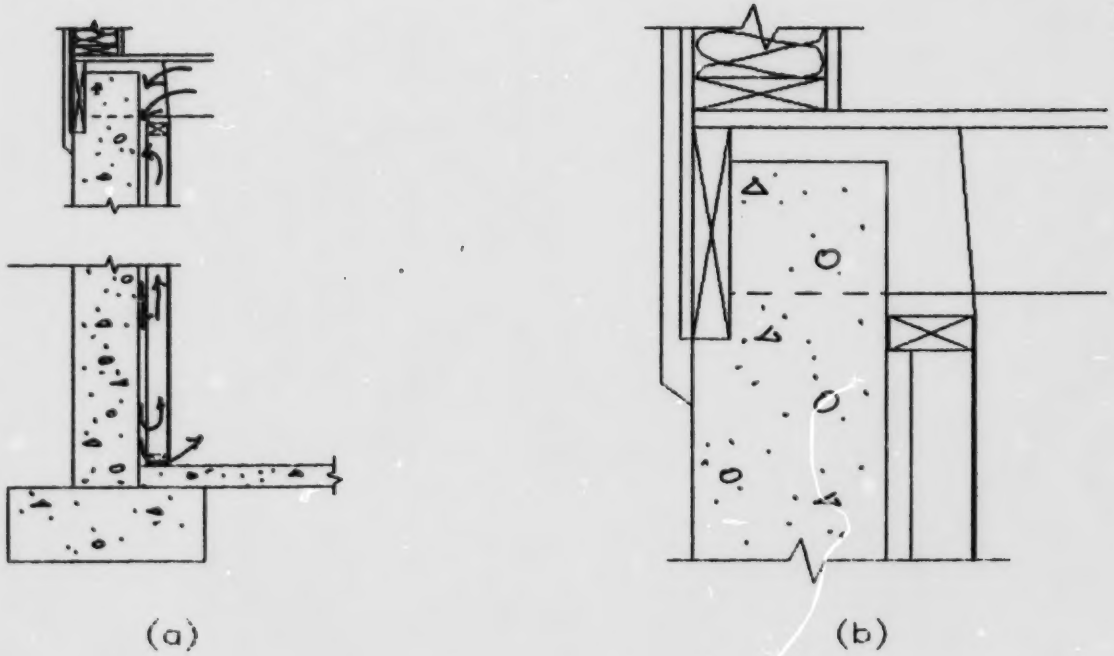


Figure 5. Basement Wall Cavity Air Circulation Pattern and Mitigative Measure:
(a) Normal air circulation (insulation removed for clarity),
(b) Air circulation barrier provided through use of oversize top plate.

6.3 FURTHER RESEARCH

The effect of improved air/vapour barrier sealing in preventing long-term moisture damage to building envelopes is well documented and currently advocated. However, whether the practice would reduce the incidence of the early basement condensation problem by eliminating the supply of moist indoor air to the concrete surface is unknown. If slow drying of the concrete contributes more to the problem, then isolating it from the interior air would probably lengthen the time of drying, as the only outlet for moisture would be via the above-grade exterior surface of the wall, where dampproofing has not been applied. More effort is therefore required into determining the relative importance of these two sources of moisture.

Modifications to conventional building practices which may help in reducing the incidence of condensation on the cool concrete of new homes, such as those suggestions of Section 6.2 above, and others, could be evaluated by trial implementation during a winter construction season and a follow-up program of observation.

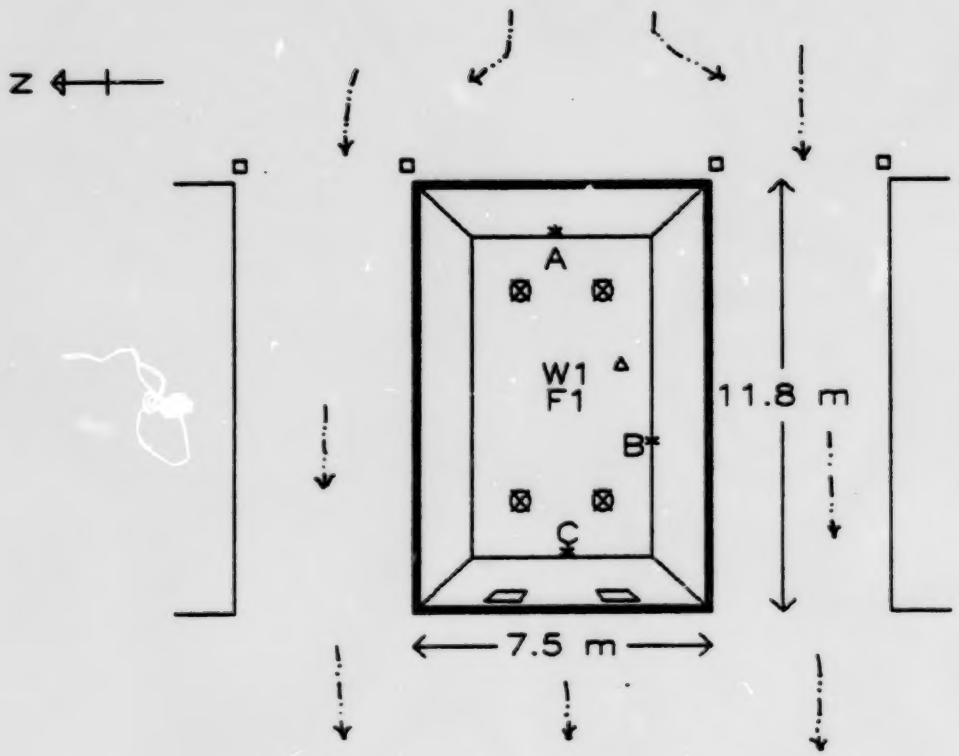
As an example, a controlled test of the effectiveness of an air circulation barrier or other similar measure could be implemented without necessarily appreciating the importance of air circulation to the problem. With the cooperation of a larger builder, a group of about ten houses could be fitted with the barrier during a winter construction season and at minimal cost and disruption, and these houses could be compared to a similar control group by observation during the following months. The results could be expected to be indicative rather than definitive, due to the many other factors which may have a role in the condensation phenomenon, but the process of observation would also provide a significant amount of insight.

Finally, it should be noted that the current project comprised direct observation of the condensation problem only during summer, and only anecdotal observation of winter practices, wall temperatures, interior moisture levels, and condensation and ice formation during that season. The understanding of the nature of Winnipeg's new home basement condensation problem could benefit greatly from a careful program of winter monitoring of susceptible houses.

APPENDIX A

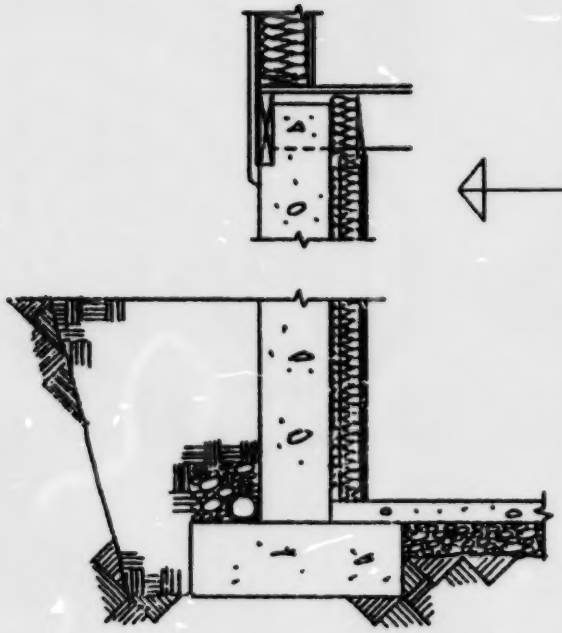
PROJECT HOUSE DESCRIPTIONS AND MONITORING DATA

HOUSE # 1



# 1	Raised bungalow constructed winter–spring 1984 Bas't separable from upper level by interior door Some basement partitions; doorways normally open
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫⟶	Downspout without/with extension
⟶	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←---●	Sump and discharge
▼/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F1	Nat. gas f/a furnace, natural aspiration, standing pilot
W1	Standard nat. gas DHW heater
	Wetted surface
Mech. Vent'n	Main floor bath fan ducted to outdoors via bas't wall Bas't clothes dryer vented outdoors via bas't wall New in spring 1987: kitchen exhaust fan, fresh air intake to return air system, bas't return air inlets

HOUSE # 1

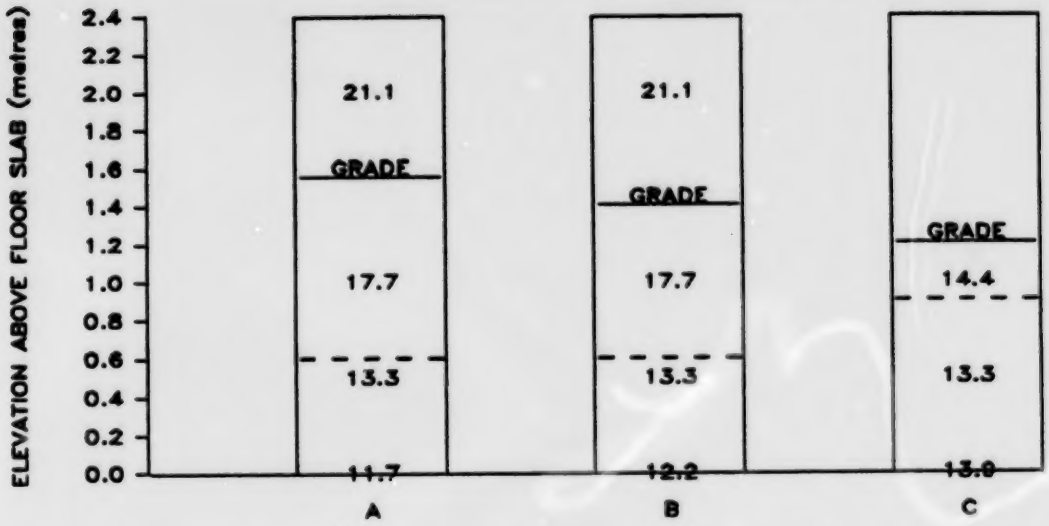


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 1.76 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)
- 13 mm drywall

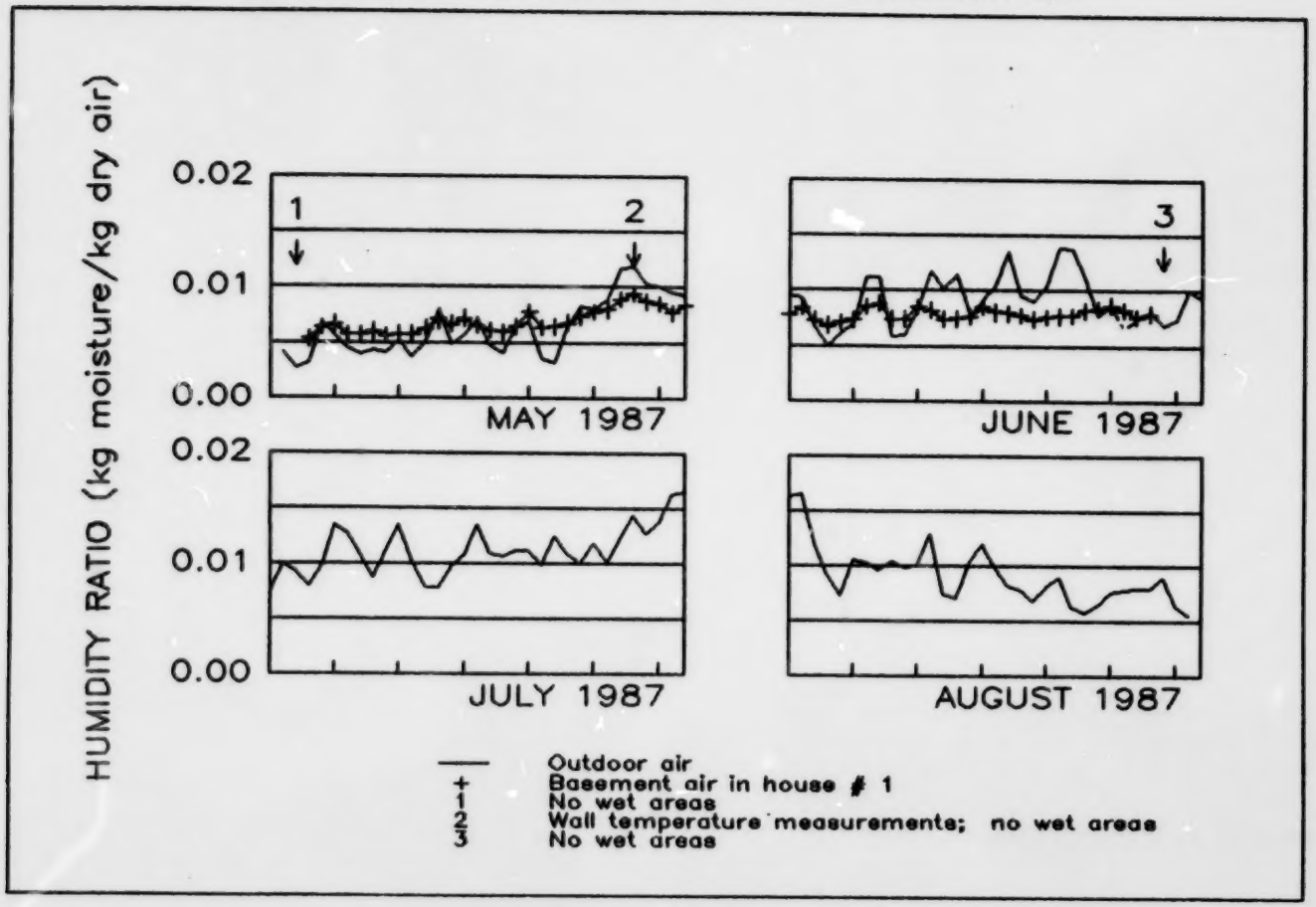
A.1.2

WALL SURFACE TEMPERATURES, HOUSE # 1

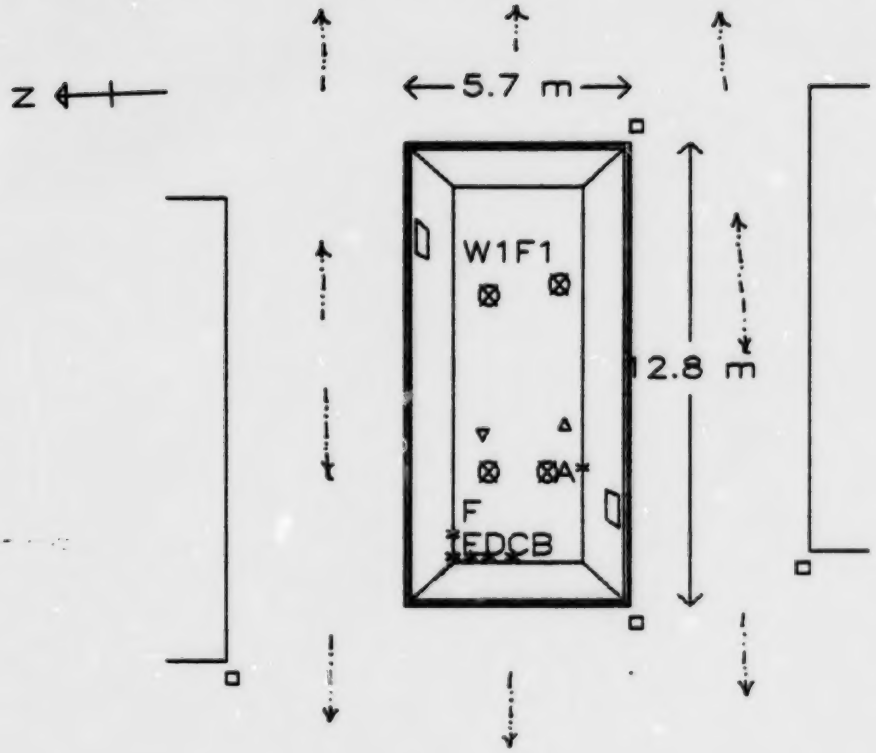


# 1	28 May 1987, 15:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
- - -	Approx. wall surface location corresponding to dewpoint of basement air
A	In northeast corner room, toward centre of east concrete wall; measurement in drywalled/insulated cavity next to section of bare wall (extends to northeast corner and approx. 3 m along north wall) which has been exposed since late winter 1987; room air can move laterally into measured cavity
B	Near mid-point of south wall, first drywalled/insulated cavity next to bared wall section which extends almost to station A; south wall from station B to southwest corner and west and north walls are still drywalled
C	Below window near centre of west wall; polyethylene and drywall not completely in place at station C
Air Temps	Basement 20.3, outdoors 18.9 (Celsius)
Humidity Ratio	Basement 0.0102 (kg moisture/kg dry air) Outdoors 0.0121; day's mean outdoors 0.0118
Comment	There has been some inflow from east lot drainage. Insulation removed several times since 1984 due to winter ice/condensation and summer condensation

HOUSE # 1: BASEMENT AIR VS OUTDOOR AIR

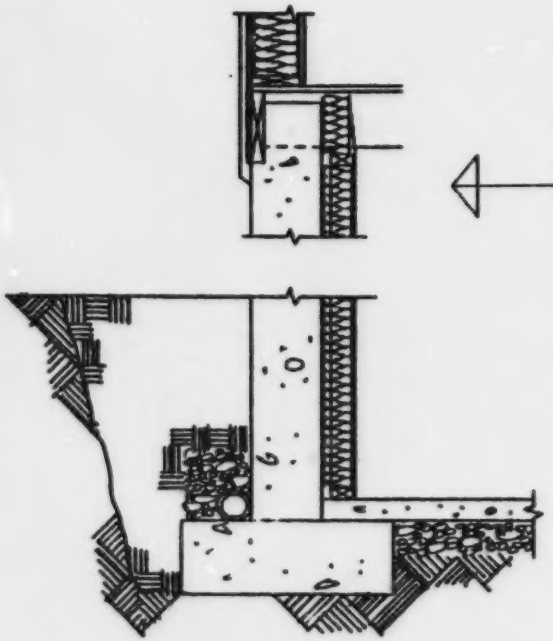


HOUSE # 2



# 2	Bungalow constructed early spring 1986 Bas't separable from upper level by interior door
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫⟶	Downspout without/with extension
┄→	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←┄⊕	Sump and discharge
▽/△	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F1	Nat. gas f/a furnace, natural aspiration, standing pilot
W1	Standard nat. gas DHW heater
▒	Wetted surface 26 May 1987
Mech. Vent'n	Main floor bath fan ducted to outdoors via bas't wall Bas't clothes dryer vented outdoors via bas't wall

HOUSE # 2

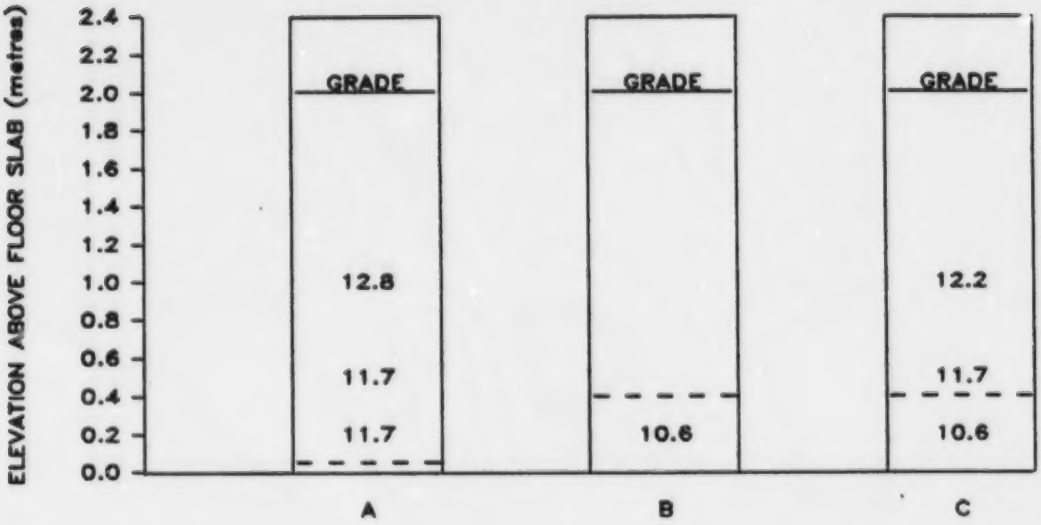


FOUNDATION WALL CONSTRUCTION

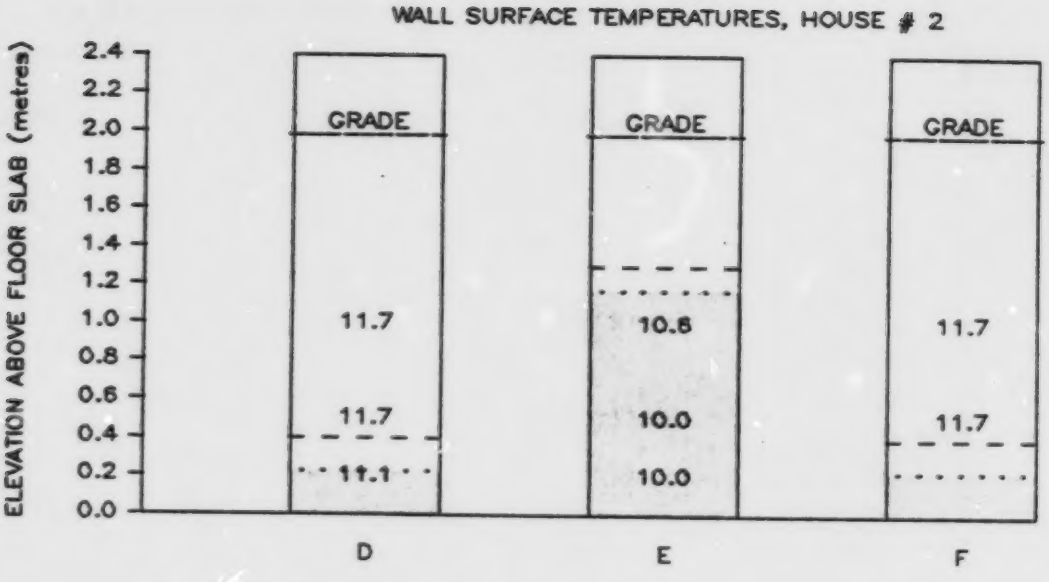
- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 1.76 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)

A.2.2

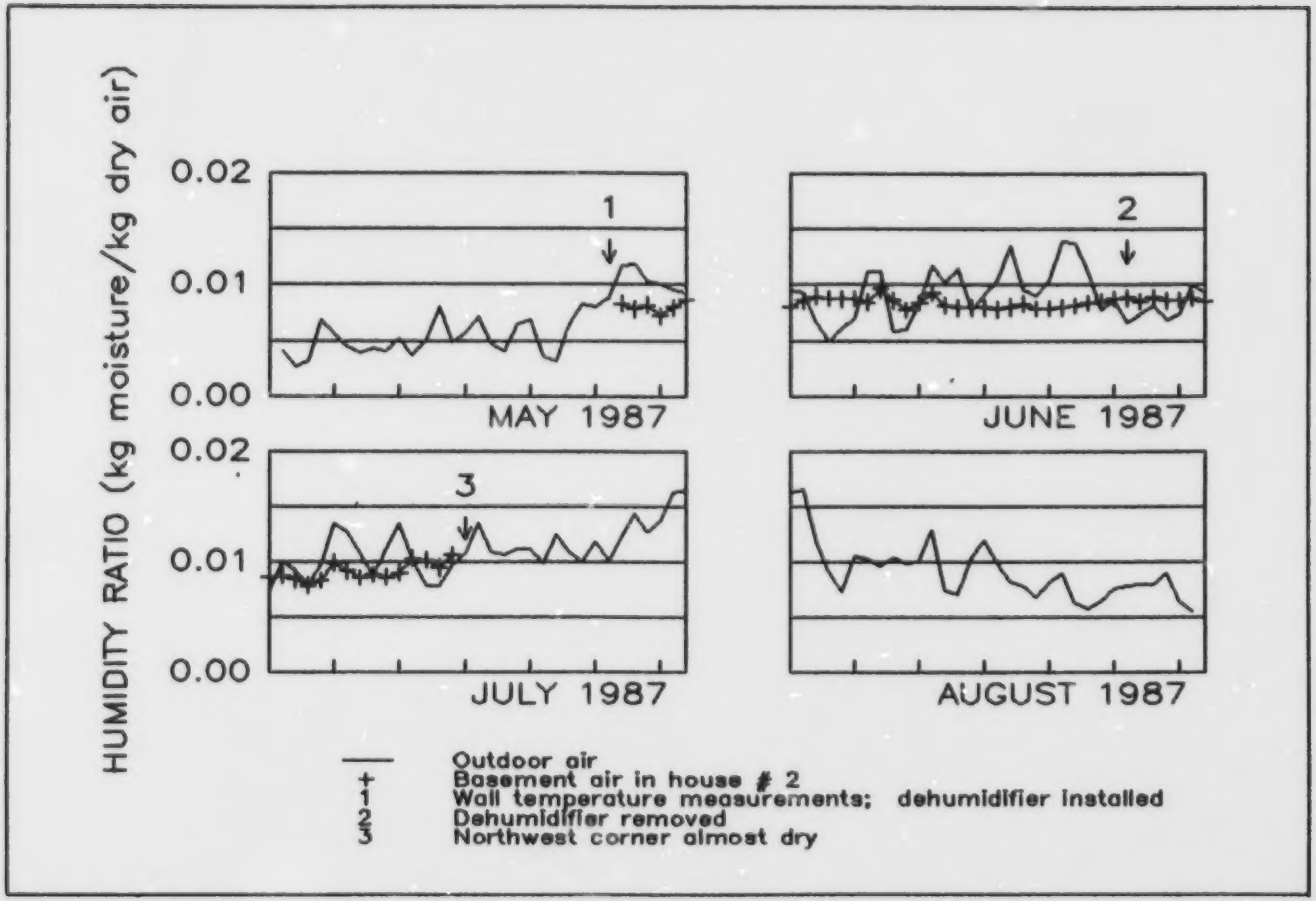
WALL SURFACE TEMPERATURES, HOUSE # 2



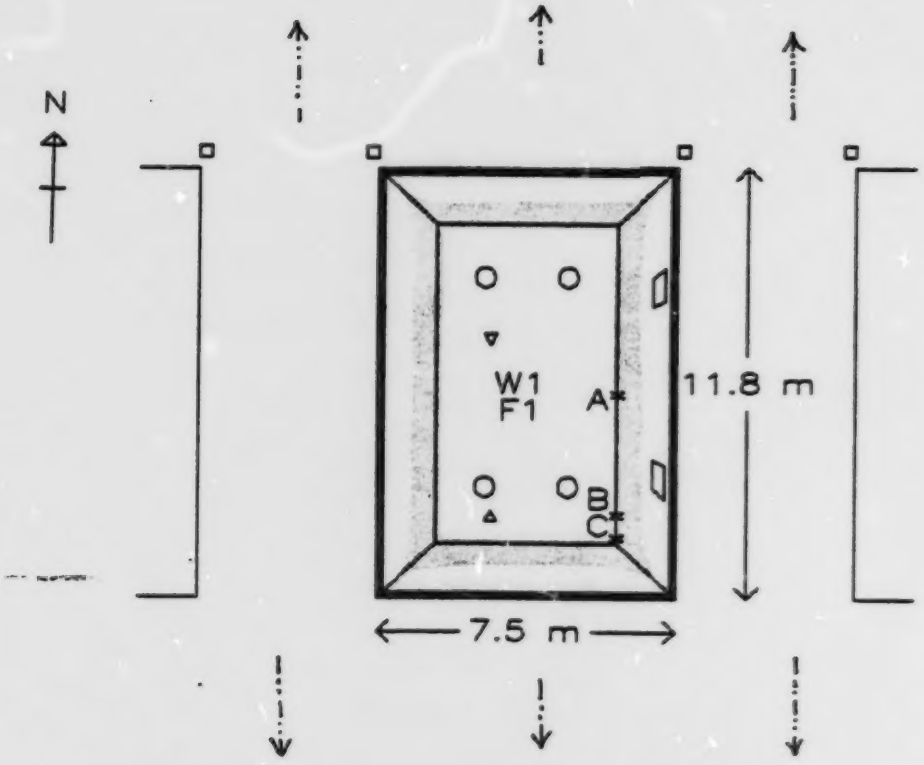
# 2	26 May 1987, 16:00 CST
▒▒▒	Wetted surface
21.3	Concrete surface temperature (Celsius)
– – –	Approx. wall surface location corresponding to dewpoint of basement air
A	3.1 m E of SW corner; poly/batts undisturbed
B	2.7 m S of NW corner; poly/batts undisturbed
C	1.1 m S of NW corner; poly/batts undisturbed
D	0.6 m S of NW corner; poly loosened at base of wall
E	NW corner; poly pulled away from wall at base
F	0.4 m E of NW corner; poly loosened at base of wall
Air Temps	Basement 18.3, outdoors 16.4 (Celsius)
Humidity Ratio	Basement 0.0085 (kg moisture/kg dry air) Outdoors 0.0090; day's mean outdoors 0.0089
Comment	Winter high-humidity problems Northwest corner has been wet since first occupancy


WALL SURFACE TEMPERATURES, HOUSE # 2
ELEVATION ABOVE FLOOR SLAB (metres)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
GRADE
GRADE
GRADE
11.7
11.7
11.1
10.8
10.0
10.0
11.7
11.7
D
E
F

HOUSE # 2: BASEMENT AIR VS OUTDOOR AIR

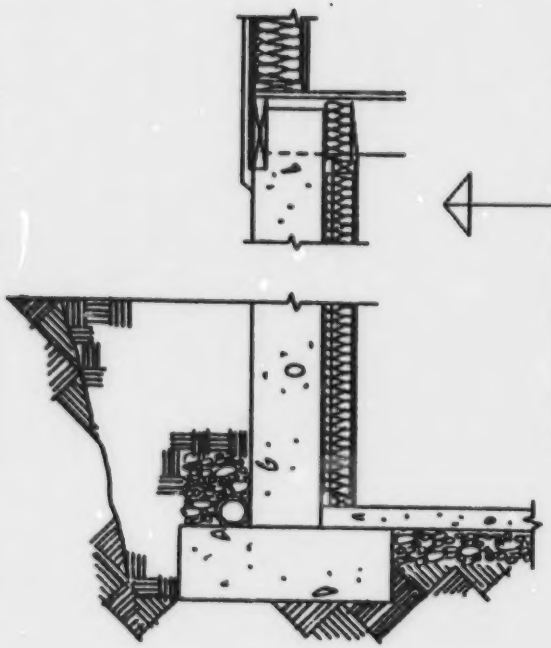


HOUSE # 3



# 3	Bungalow constructed late winter 1987
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫⟶	Downspout without/with extension
⋯→	Site surface drainage
○/⊠	Bas't supply air outlet without/with damper
←⋯⊕	Sump and discharge
▽/△	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F1	Nat. gas f/a furnace, natural aspiration, standing pilot
W1	Standard nat. gas DHW heater
▒	Wetted surface 27 May 1987
Mech. Vent'n	Main floor bath fan ducted to outdoors via bas't wall

HOUSE # 3

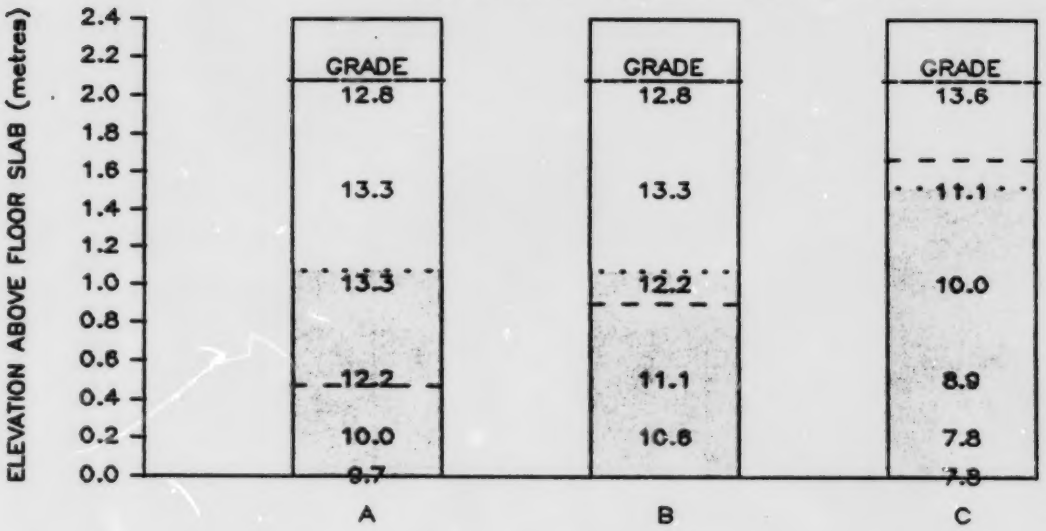


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 1.76 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)

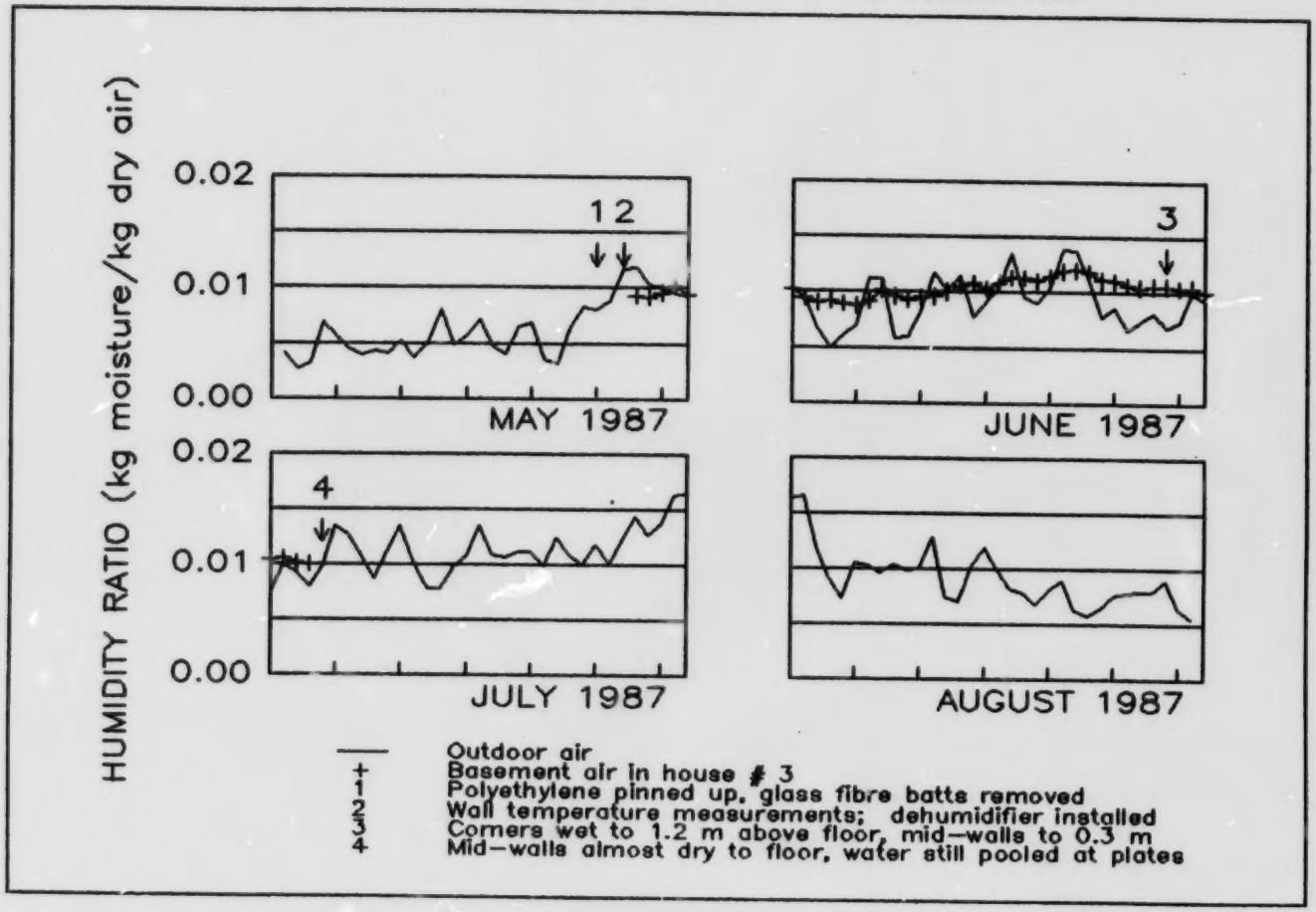
A.3.2

WALL SURFACE TEMPERATURES, HOUSE # 3

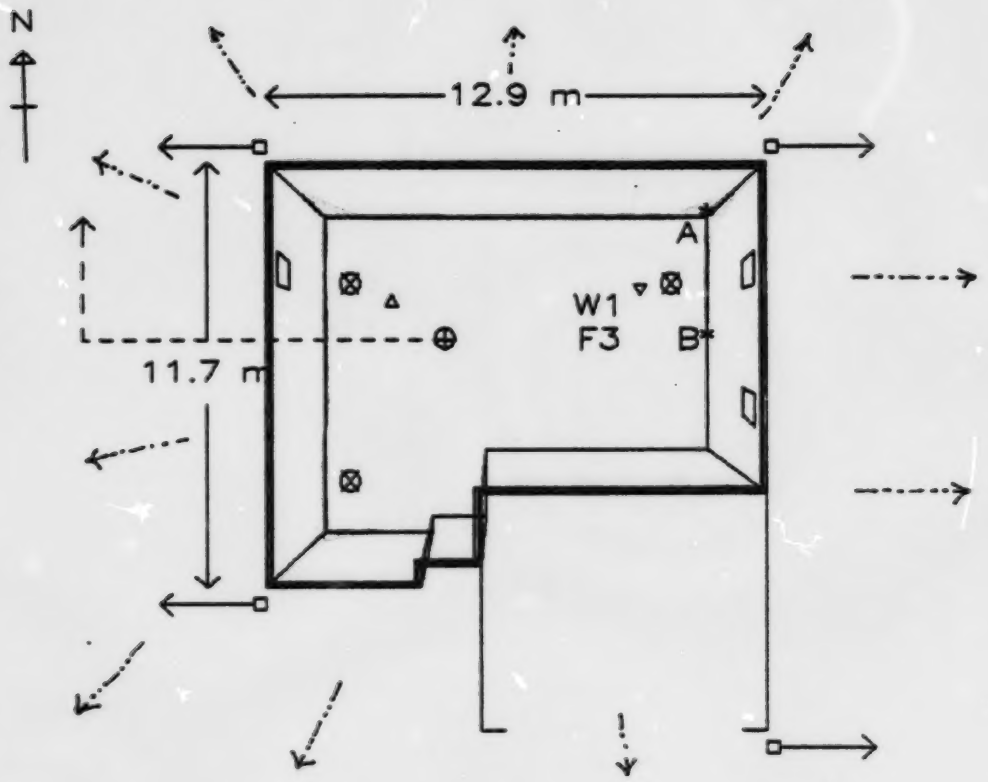


# 3	27 May 1987, 16:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
- - -	Approx. wall surface location corresponding to dewpoint of basement air
A	Near mid-wall
B	0.4 m N of SE corner
C	SE corner
Air Temps	Basement 16.9, outdoors 23.3 (Celsius)
Humidity Ratio	Basement 0.0088 (kg moisture/kg dry air) Outdoors 0.0127; day's mean outdoors 0.0117
Comment	Basement cool due to newly exposed cold walls Poly pinned up and batts removed 25 May Dehumidifier operated intermittently

HOUSE # 3: BASEMENT AIR VS OUTDOOR AIR

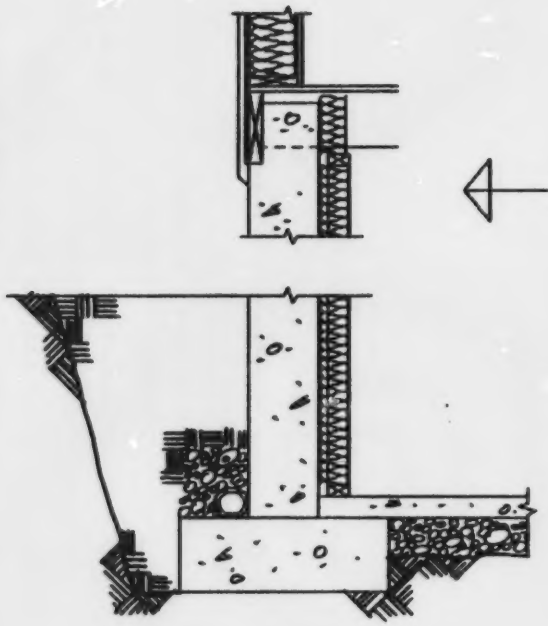


HOUSE # 4



# 4	Bungalow constructed winter–spring 1986 Bas't separable from upper level by interior door
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫→	Downspout without/with extension
---→	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←---⊕	Sump and discharge
▾/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F3	Nat. gas f/a furnace, high–efficiency condensing type
W1	Standard nat. gas DHW heater
▒	Wetted surface 17 June 1987
Mech. Vent'n	Central exhaust system ducted out via bas't wall: three main floor inlets (kitchen, two baths) Main floor clothes dryer vented out via main floor wall Undampered fresh air intake to return air system Main floor fireplace

HOUSE # 4

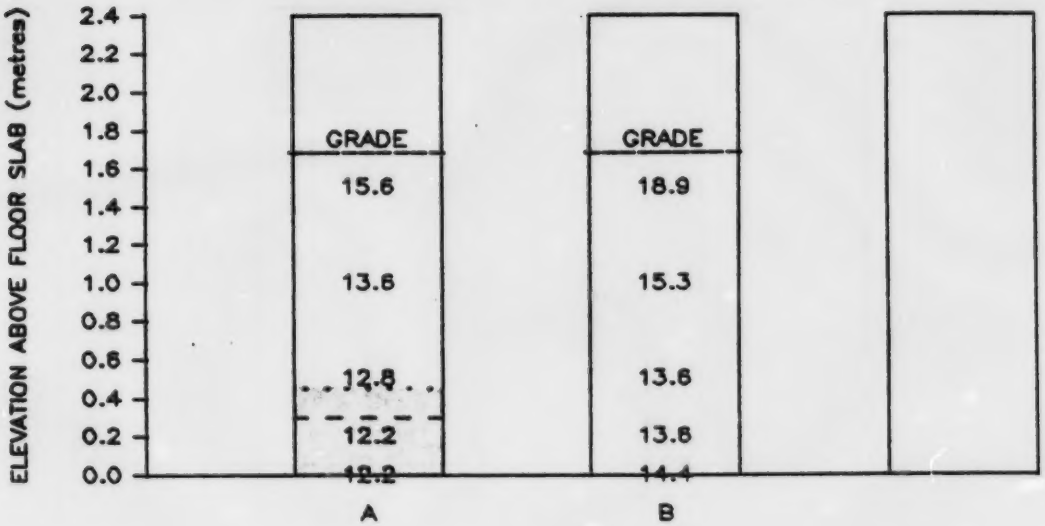


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 2.1 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- no vapour retarder installed
- no interior finish installed

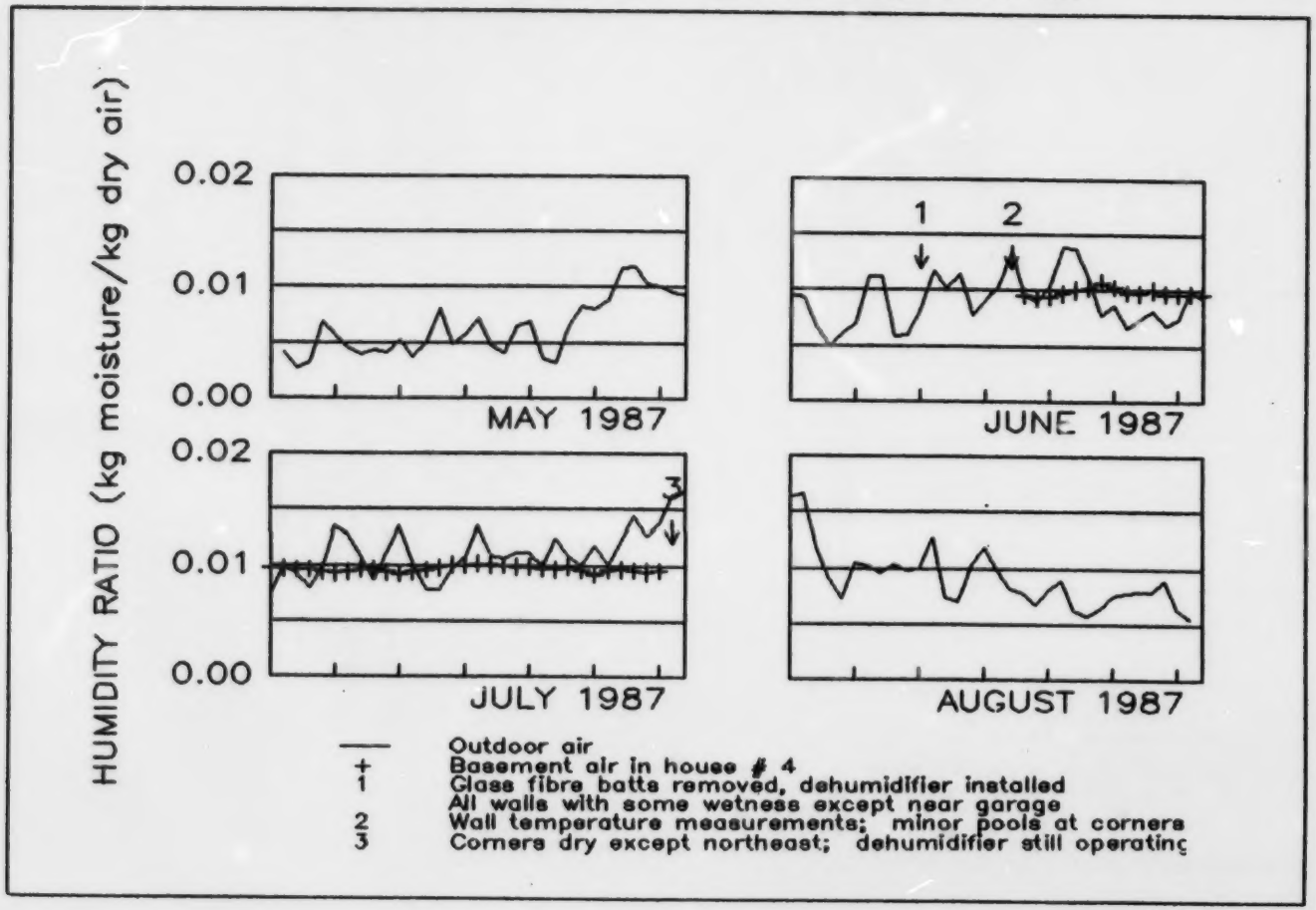
A.4.2

WALL SURFACE TEMPERATURES, HOUSE # 4

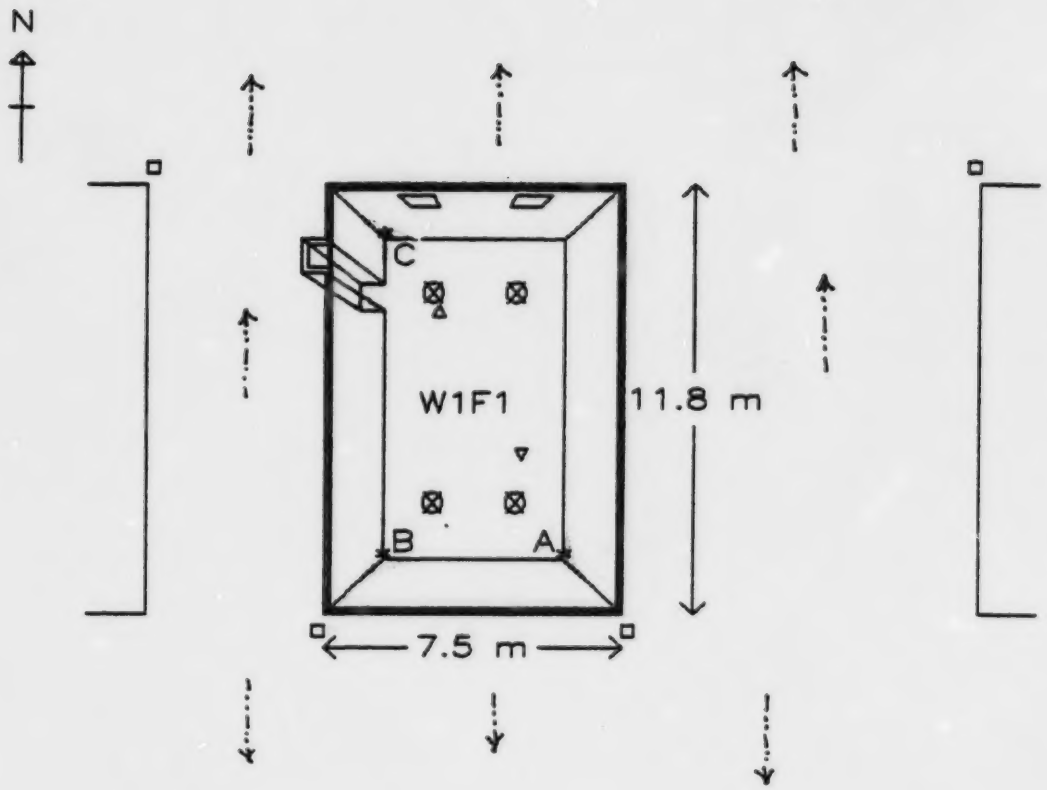


# 4	17 June 1987, 18:30 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
– – –	Approx. wall surface location corresponding to dewpoint of basement air
A	NE corner; wet batts removed approx. 10 June
B	Approx. mid-wall; batts undisturbed (not wet)
Air Temps	Basement 17.8, outdoors 22.5 (Celsius)
Humidity Ratio	Basement 0.0090 (kg moisture/kg dry air) Outdoors 0.0120; day's mean outdoors 0.0135
Comment	No polyethylene installed History unknown; new owners June 1987

HOUSE # 4: BASEMENT AIR VS OUTDOOR AIR

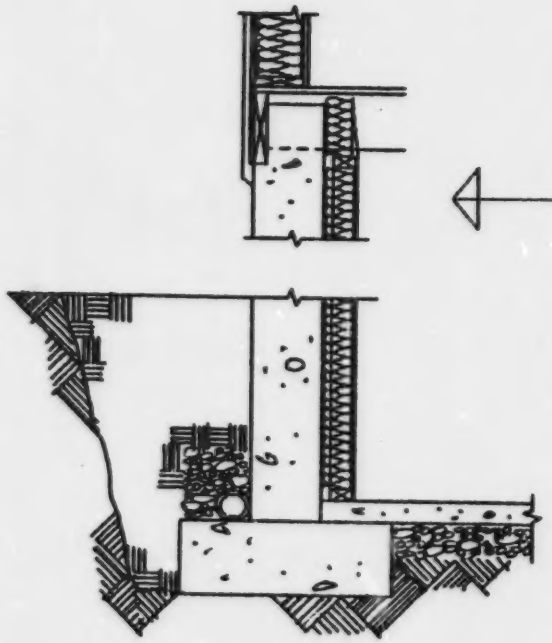


HOUSE # 5



# 5	Raised bungalow constructed winter–spring 1987 Bas't separable from upper level by interior door
———	Insulated/uninsulated portion of concrete wall
▫/▫→	Downspout without/with extension
---→	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←--⊕	Sump and discharge
▾/▴	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F1	Nat. gas f/a furnace, natural aspiration, standing pilot
W1	Standard nat. gas DHW heater
▒	Wetted surface 6 July 1987
Mech. Vent'n	Main floor bath fan ducted to outdoors via bas't wall Bas't clothes dryer vented outdoors via bas't wall Main floor fireplace

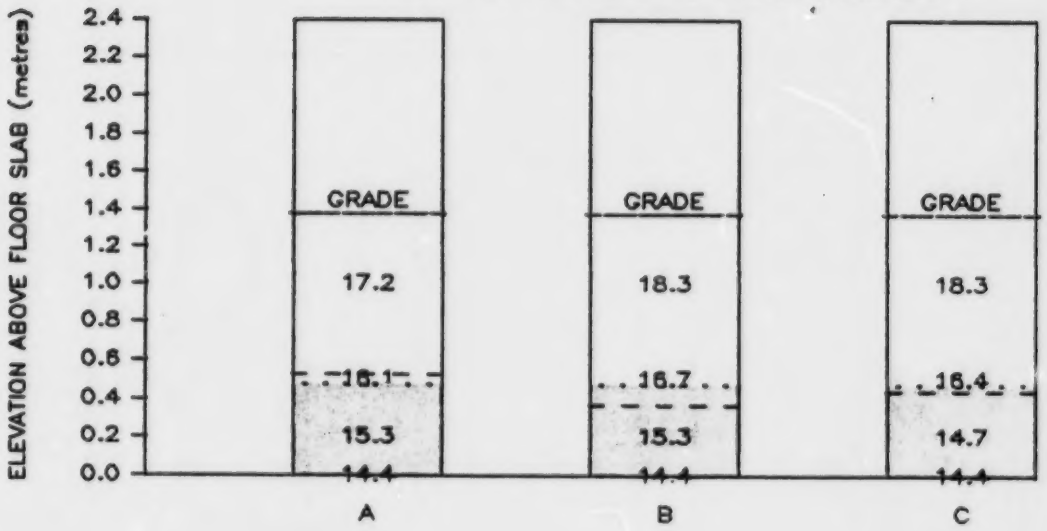
HOUSE # 5



FOUNDATION WALL CONSTRUCTION

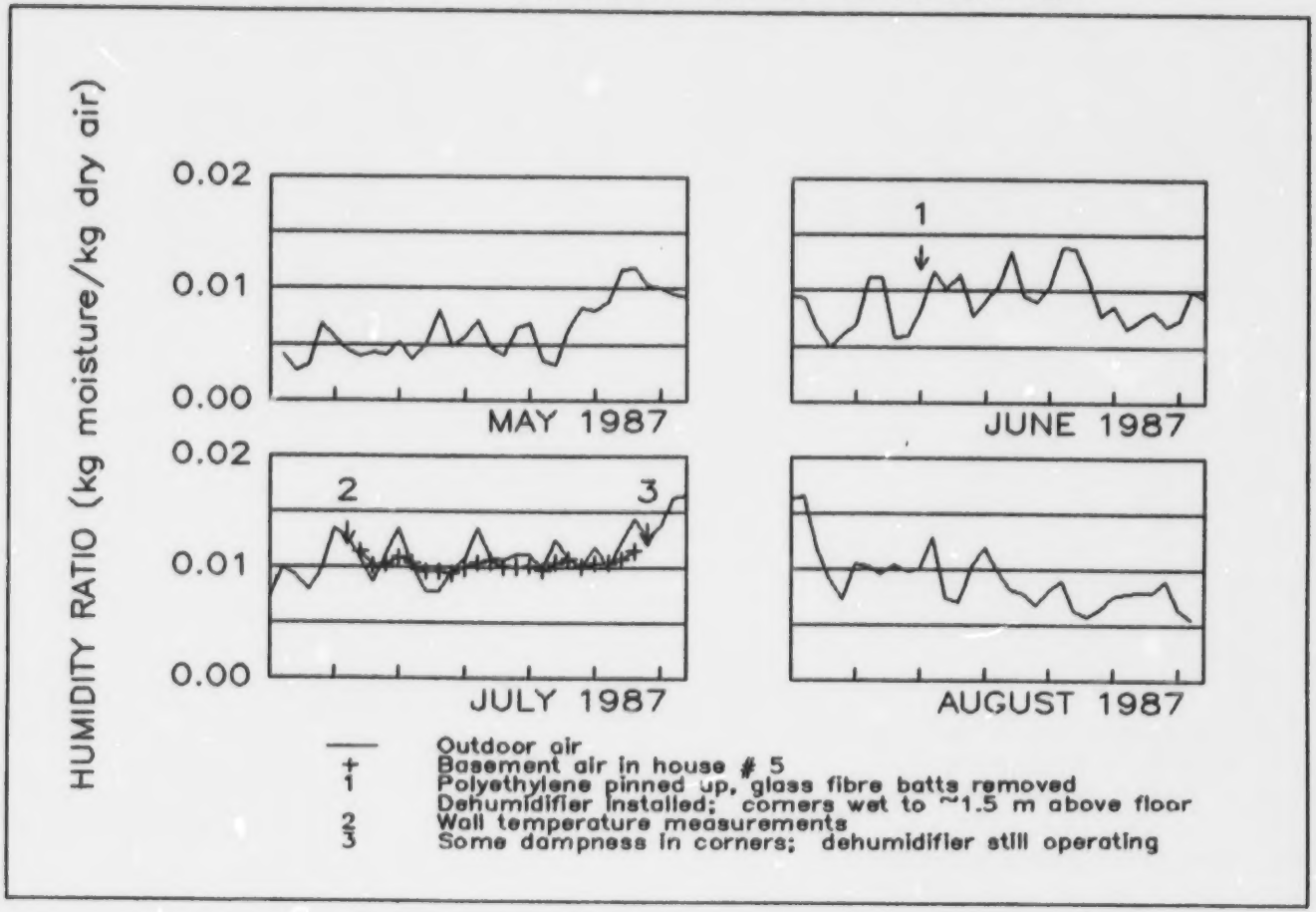
- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 1.76 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)

WALL SURFACE TEMPERATURES, HOUSE # 5

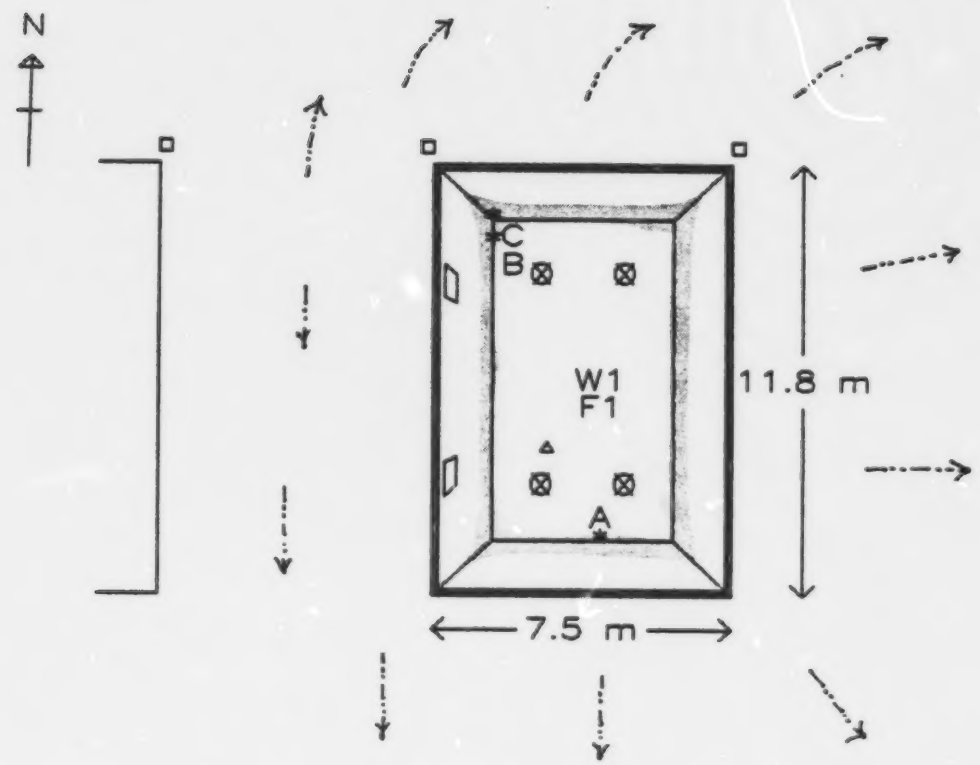


# 5	6 July 1987, 10:30 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
- - -	Approx. wall surface location corresponding to dewpoint of basement air
A	SE corner
B	SW corner
C	NW corner
Air Temps	Basement 23.8, outdoors 24.4 (Celsius)
Humidity Ratio	Basement 0.0115 (kg moisture/kg dry air) Outdoors 0.0134; day's mean outdoors 0.0127
Comment	All poly pinned up and batts removed approx. 8 June Windows open for ventilation

HOUSE # 5: BASEMENT AIR VS OUTDOOR AIR

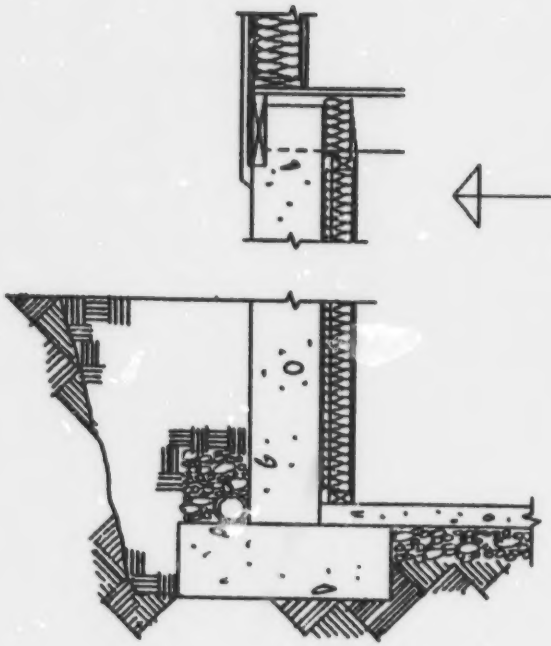


HOUSE # 6



# 6	Bungalow constructed winter–spring 1987
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫⟶	Downspout without/with extension
- - -→	Site surface drainage
○/⊠	Bas't supply air outlet without/with damper
←- -⊕	Sump and discharge
▾/▴	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F1	Nat. gas f/a furnace, natural aspiration, standing pilot
W1	Standard nat. gas DHW heater
▒	Wetted surface 15 July 1987
Mech. Vent'n	Main floor bath fan ducted to outdoors via bas't wall Bas't clothes dryer vented outdoors via bas't wall

HOUSE # 6

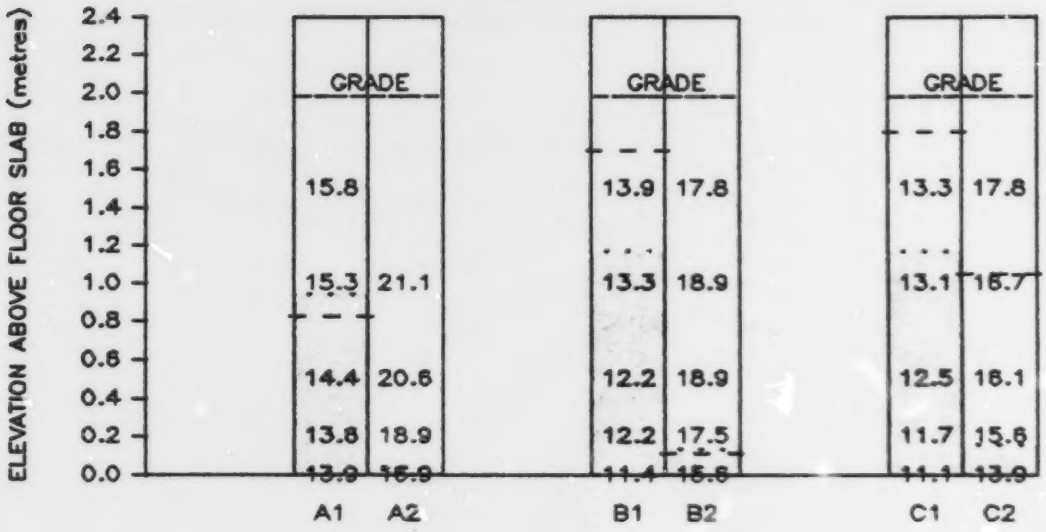


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 1.76 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)

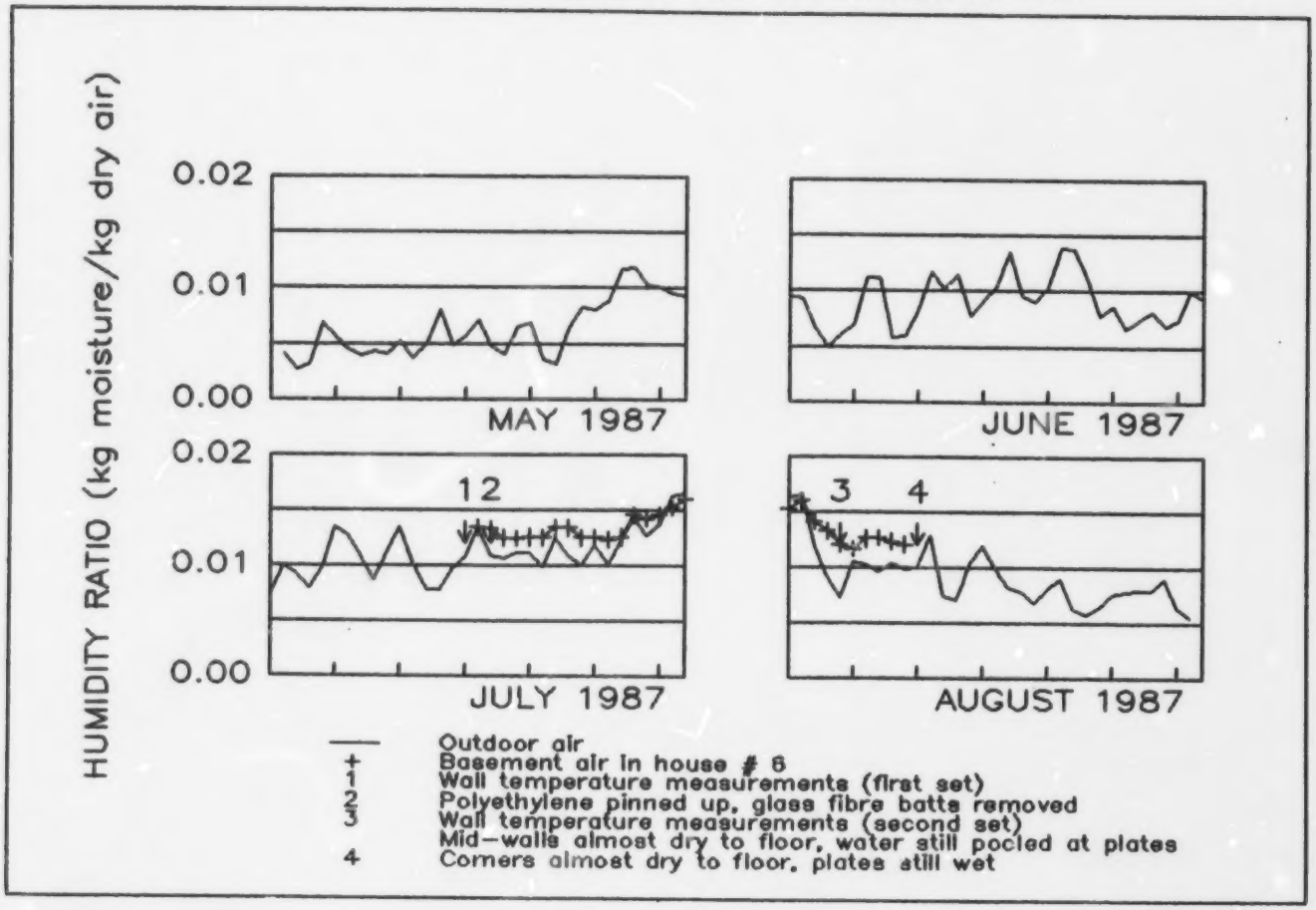
A.6.2

WALL SURFACE TEMPERATURES, HOUSE # 6

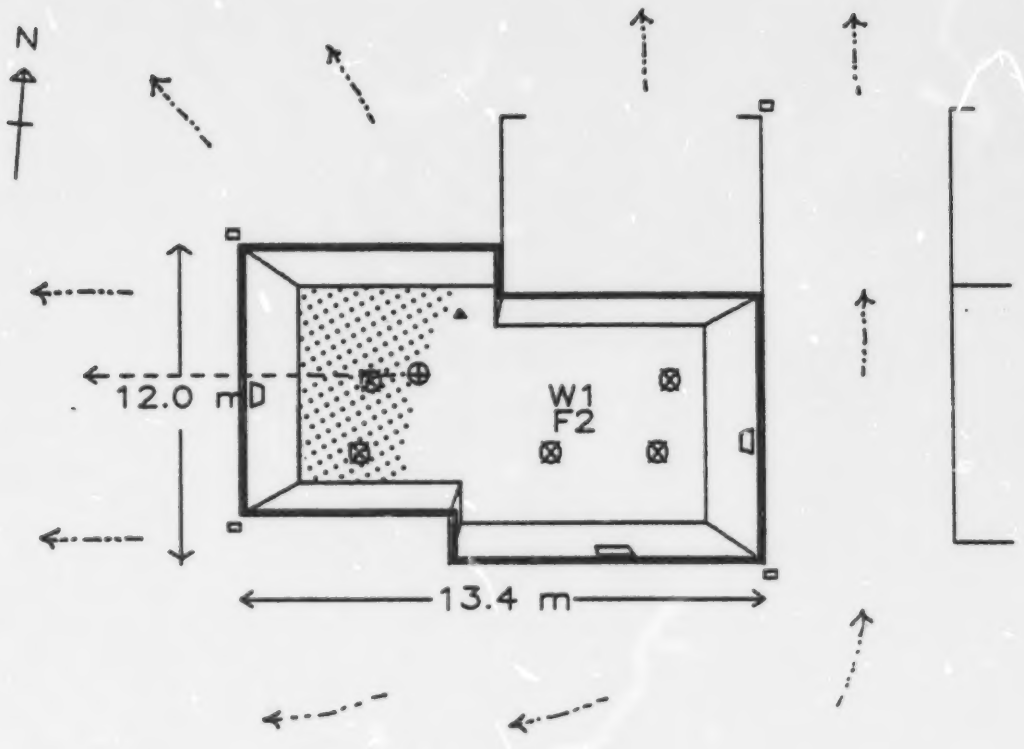


# 6	15 July 1987, 13:00 CST; 4 August 1987, 10:30 CST
.	Wetted surface
21.3	Concrete surface temperature (Celsius)
– – –	Approx. wall surface location corresponding to dewpoint of basement air
A	Near midpoint of S wall
B	0.5 m S of NW corner
C	NW corner
	15 July:
Air Temps	Basement 22.2, outdoors 23.9 (Celsius)
Humidity Ratio	Basement 0.0107 (kg moisture/kg dry air) Outdoors 0.0107; day's mean outdoors 0.0108
	4 August:
Air Temps	Basement 21.7, outdoors 18.3 (Celsius)
Humidity Ratio	Basement 0.0120 (kg moisture/kg dry air) Outdoors 0.0065; day's mean outdoors 0.0072
Comment	Walls undisturbed prior to first set of measurements Poly pinned up and batts removed after first visit Walls bare for second set of measurements

HOUSE # 6: BASEMENT AIR VS OUTDOOR AIR

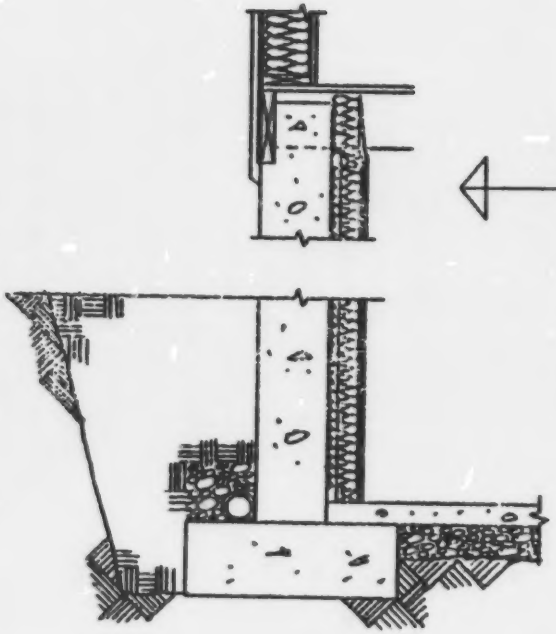

HUMIDITY RATIO (kg moisture/kg dry air)
0.02
0.01
0.00
MAY 1987
JUNE 1987
12
3 4
JULY 1987
AUGUST 1987
Outdoor air
+ Basement air in house # 6
1 Wall temperature measurements (first set)
2 Polyethylene pinned up, glass fibre batts removed
3 Wall temperature measurements (second set)
Mid-walls almost dry to floor, water still pooled at plates
4 Corners almost dry to floor, plates still wet

HOUSE # 7



# 7	Bungalow constructed winter–spring 1986 Bas't separable from upper level by interior door
———	Insulated/uninsulated portion of concrete wall
o/o⟶	Downspout without/with extension
- - -→	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←- -◈	Sump and discharge
▾/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F2	Nat. gas f/a furnace, spark ignition, vent damper
W1	Standard nat. gas DHW heater
▒	Wetted surface 16 July 1987
⁘	Damp surface with efflorescence 16 July 1987
Mech. Vent'n	3 exhaust fans ducted to outdoors on main level Main floor clothes dryer vented outdoors via bas't wall Undampered fresh air intake to return air system Main floor fireplace

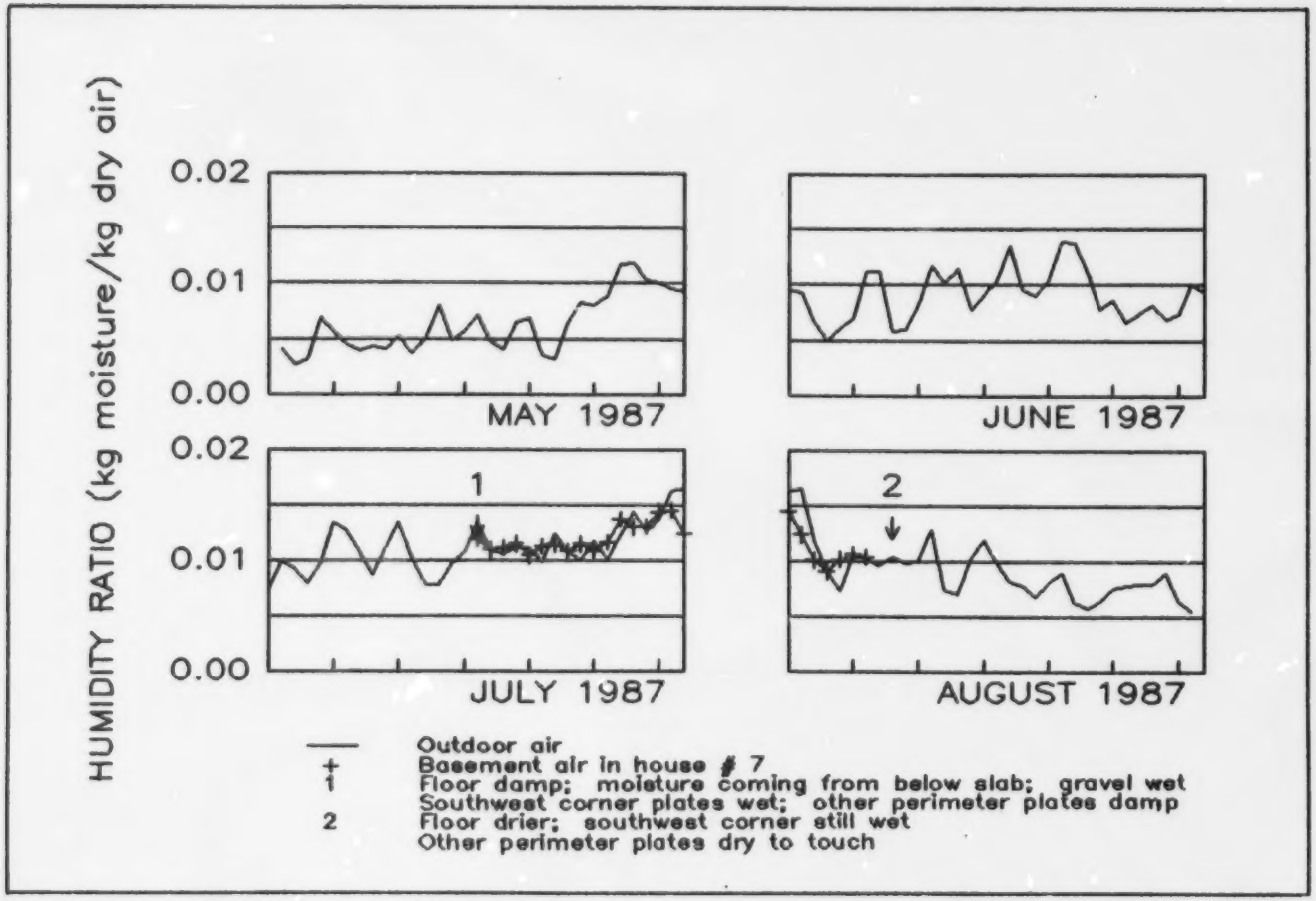
HOUSE # 7



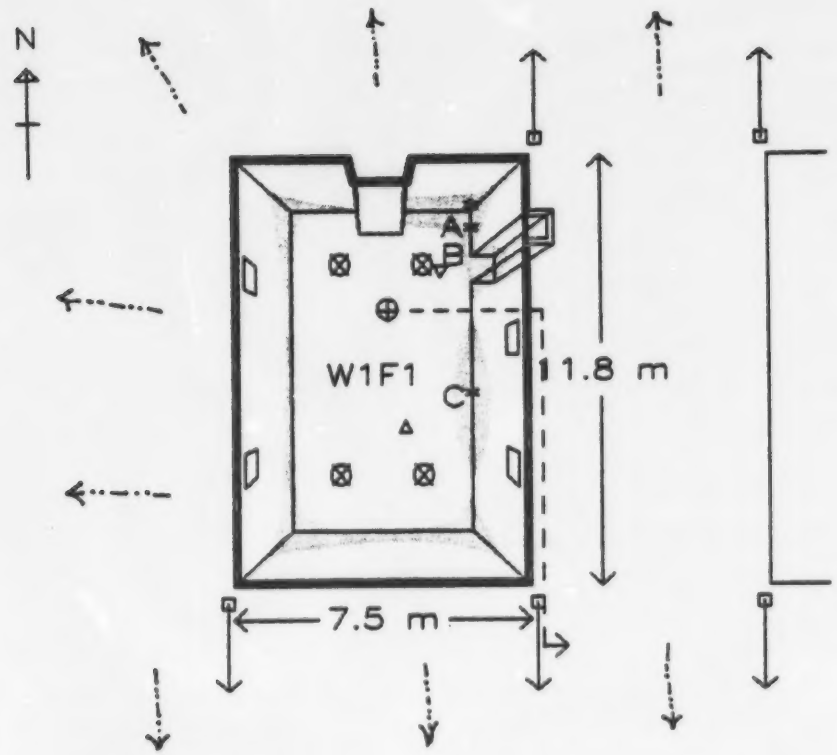
FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 2.1 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)
- 13 mm drywall

HOUSE # 7: BASEMENT AIR VS OUTDOOR AIR

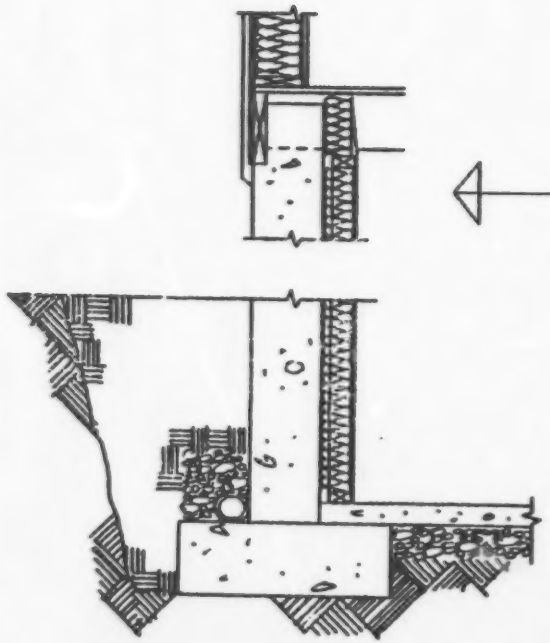


HOUSE # 8



# 8	Bungalow constructed winter–spring 1987 Bas't separable from upper level by interior door
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫⟶	Downspout without/with extension
⟶	Site surface drainage
⊙/⊠	Bas't supply air outlet without/with damper
←⊕	Sump and discharge
▾/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F1	Nat. gas f/a furnace, natural aspiration, standing pilot
W1	Standard nat. gas DHW heater
▒	Wetted surface 11 August 1987
Mech. Vent'n	2 main floor bath fans ducted to outdoors via bas't wall Bas't clothes dryer vented outdoors via bas't wall Main floor fireplace

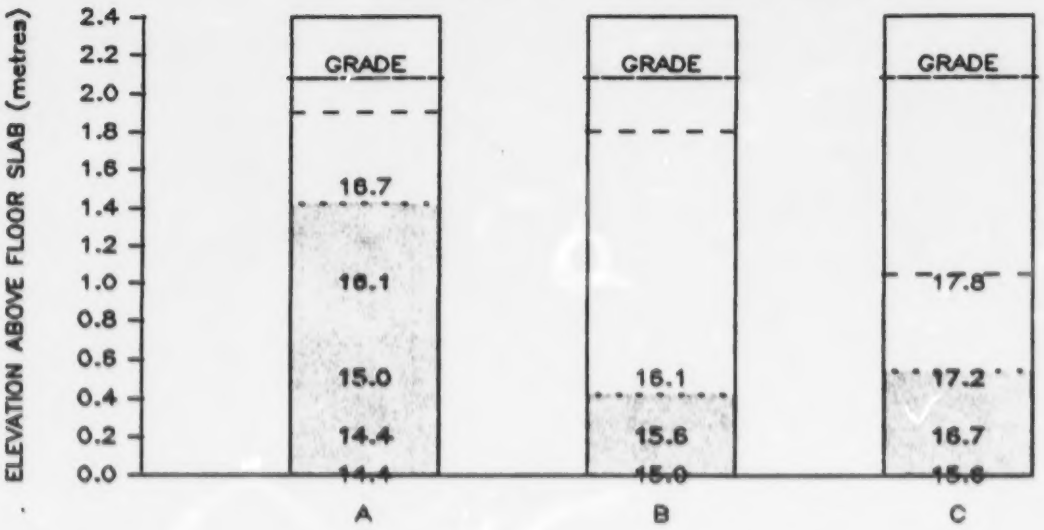
HOUSE # 8



FOUNDATION WALL CONSTRUCTION

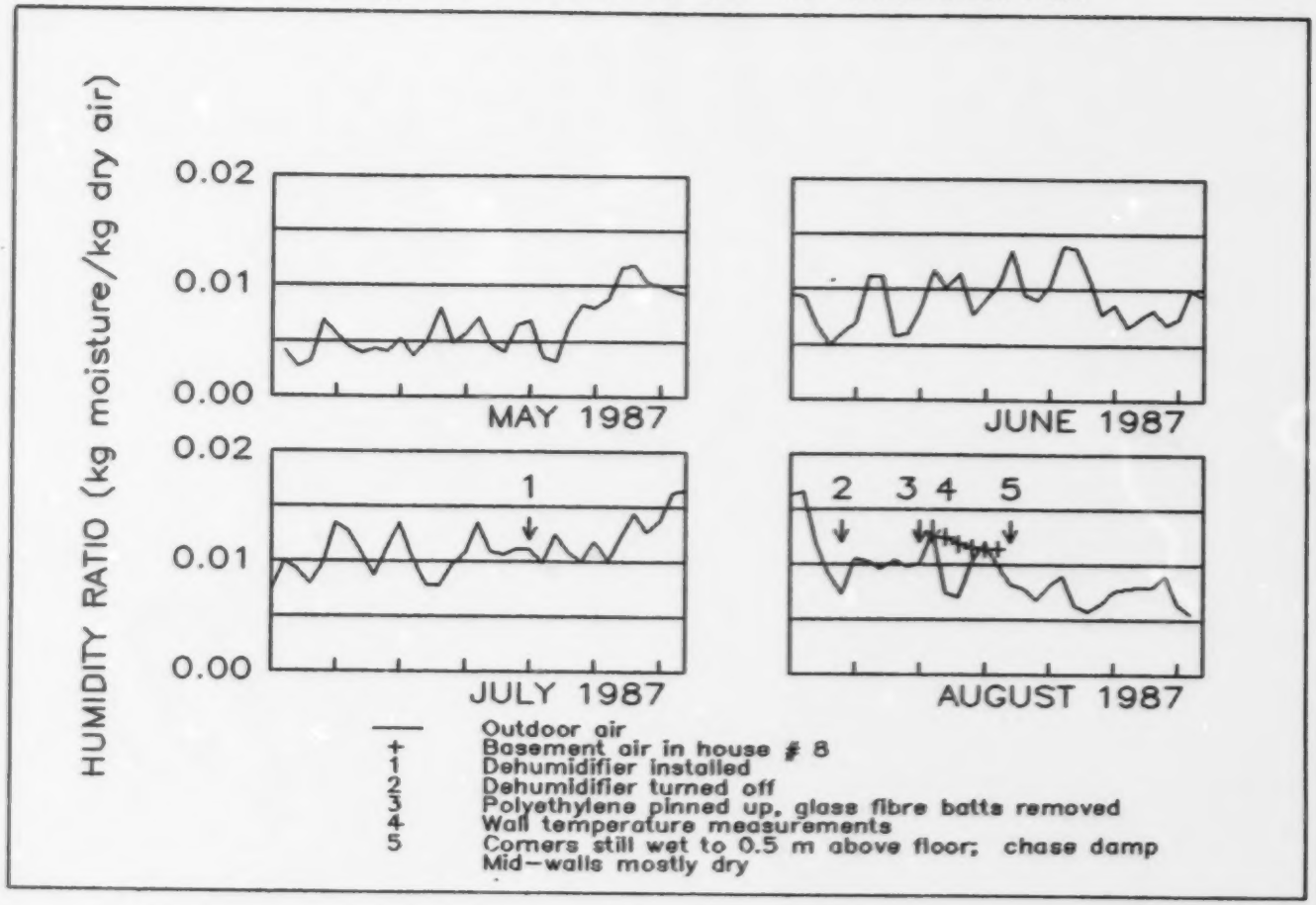
- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 1.76 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)

WALL SURFACE TEMPERATURES, HOUSE # 8

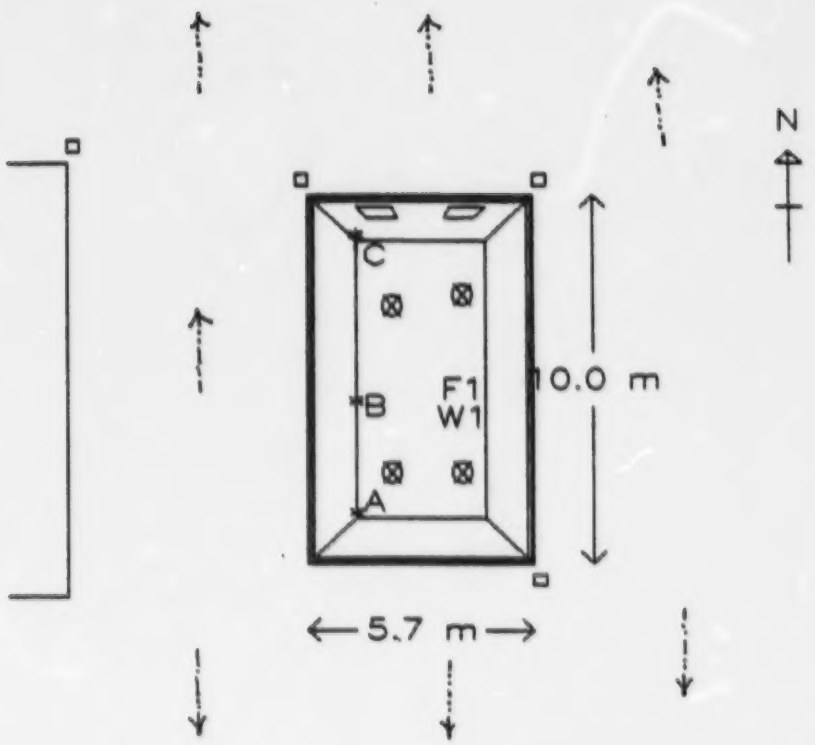


# 8	11 August 1987, 9:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
- - -	Approx. wall surface location corresponding to dewpoint of basement air
A	NE corner
B	0.4 m S of NE corner
C	Approx. midpoint of E wall
Air Temps	Basement 20.3, outdoors 21.1 (Celsius)
Humidity Ratio	Basement 0.0129 (kg moisture/kg dry air) Outdoors 0.0137; day's mean outdoors 0.0128
Comment	Poly pinned up and batts removed 10 August

HOUSE # 8: BASEMENT AIR VS OUTDOOR AIR

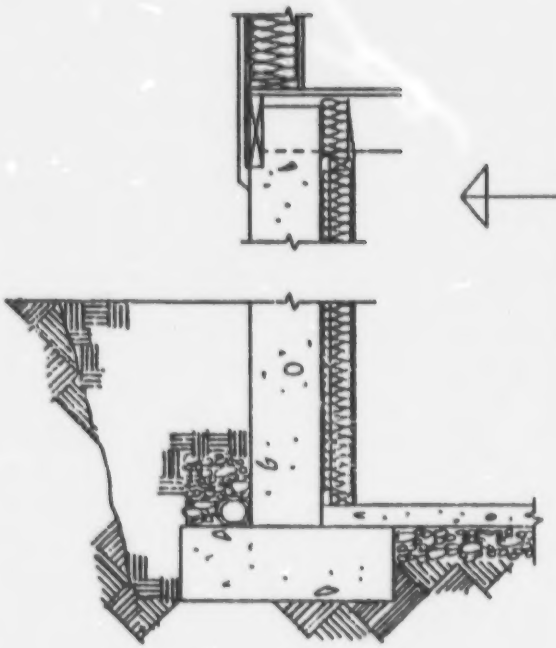


HOUSE # 9



# 9	Raised bungalow constructed summer 1987 Occupied 1 September 1987
———	Insulated/uninsulated portion of concrete wall
o/o⟶	Downspout without/with extension
-·-·-/-·-·->	Site surface drainage
O/⊠	Bas't supply air outlet without/with damper
←---●	Sump and discharge
▼/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F1	Nat. gas f/a furnace, natural aspiration, standing pilot
W1	Standard nat. gas DHW heater
	Wetted surface 11 August 1987
Mech. Vent'n	Main floor bath exhaust fan

HOUSE # 9

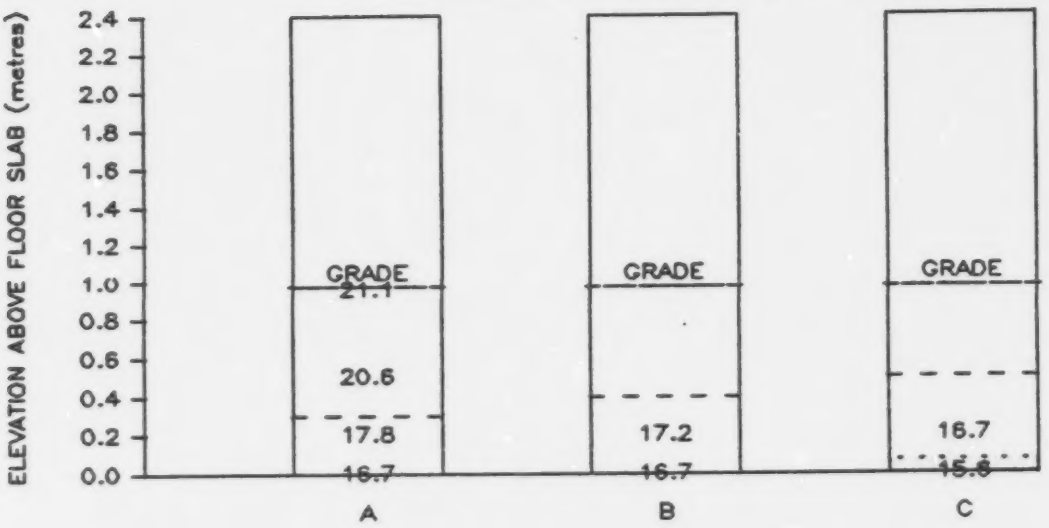


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 1.76 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)

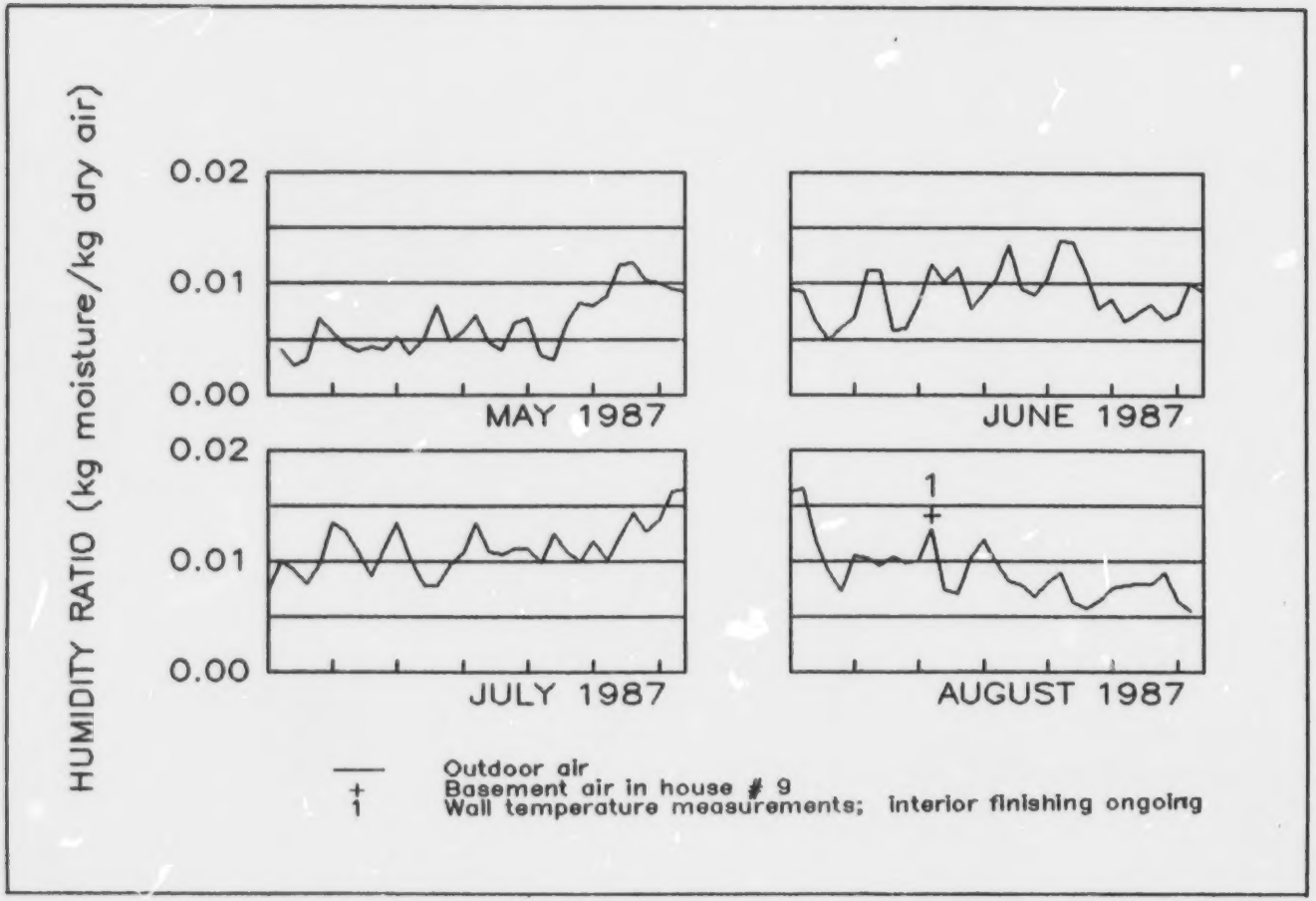
A.9.2

WALL SURFACE TEMPERATURES, HOUSE # 9

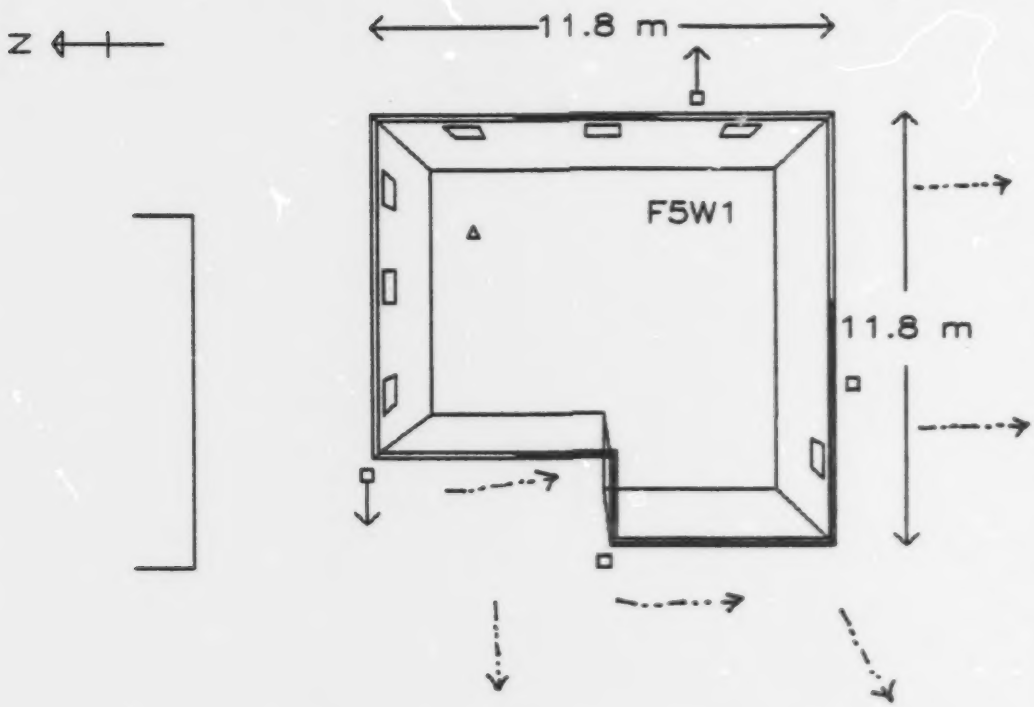


# 9	11 August 1987, 14:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
- - -	Approx. wall surface location corresponding to dewpoint of basement air
A	SW corner; poly/batts undisturbed
B	Approx. midpoint of W wall; poly/batts undisturbed
C	NW corner; poly/batts undisturbed
Air Temps	Basement 20.4, outdoors 23.9 (Celsius)
Humidity Ratio	Basement 0.0135 (kg moisture/kg dry air) Outdoors 0.0140; day's mean outdoors 0.0128
Comment	Finishing of interior of house is in progress Door and windows often open

HOUSE # 9: BASEMENT AIR VS OUTDOOR AIR

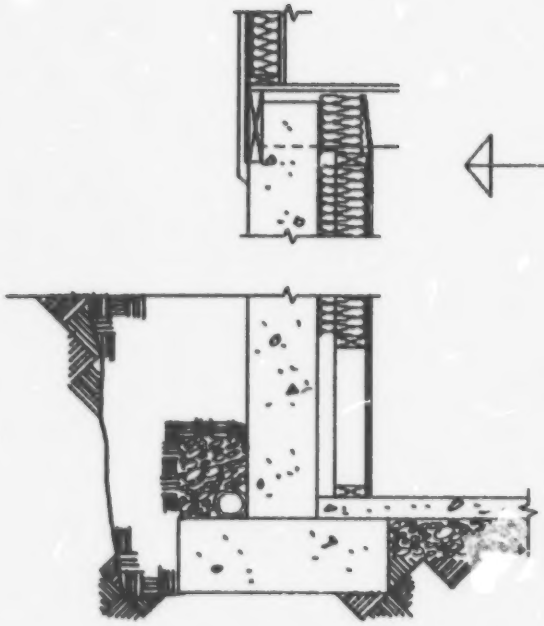


HOUSE # 10



# 10	Bungalow constructed in 1954 Some basement partitions; doorways normally open
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫⟶	Downspout without/with extension
---→	Site surface drainage
○/⊠	Bas't supply air outlet without/with damper
←--⊕	Sump and discharge
▾/▴	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F5	Nat. gas boiler, natural aspiration, standing pilot No radiators in basement, no supplemental heaters
W1	Standard nat. gas DHW heater
▒	Wetted surface
Mech. Vent'n	No room exhaust fans Bas't clothes dryer vented outdoors via bas't wall

HOUSE # 10

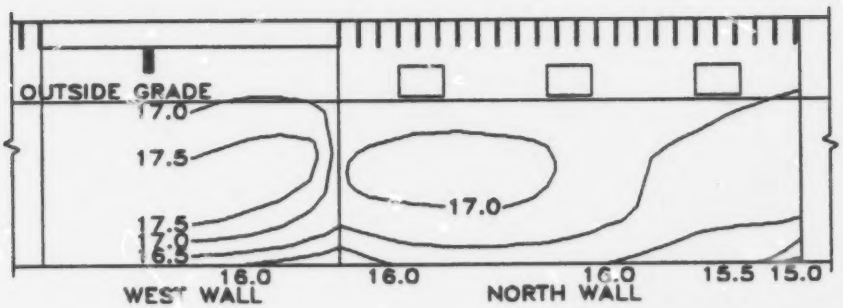


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 225 mm reinforced concrete wall
- RSI 3.5 batt insulation to 600 mm above floor
- 38x89 mm studs @ 400 mm O.C. set back 50 mm from concrete wall
- 6 mil polyethylene film stapled and caulked to studs, plates, sides of floor joists, underside of subfloor, and where lap-jointed
- 13 mm drywall

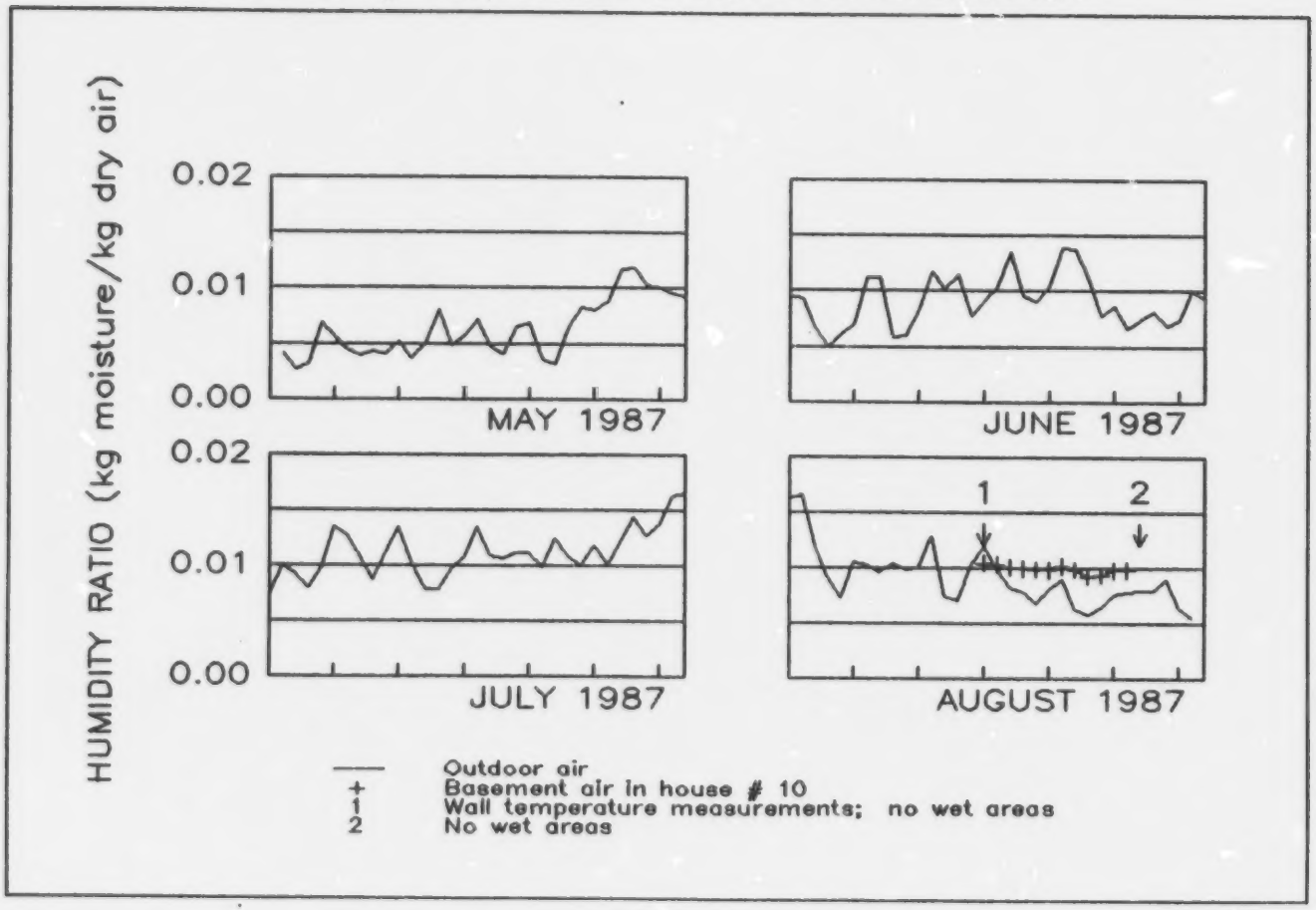
A.10.2

WALL SURFACE TEMPERATURES, HOUSE # 10

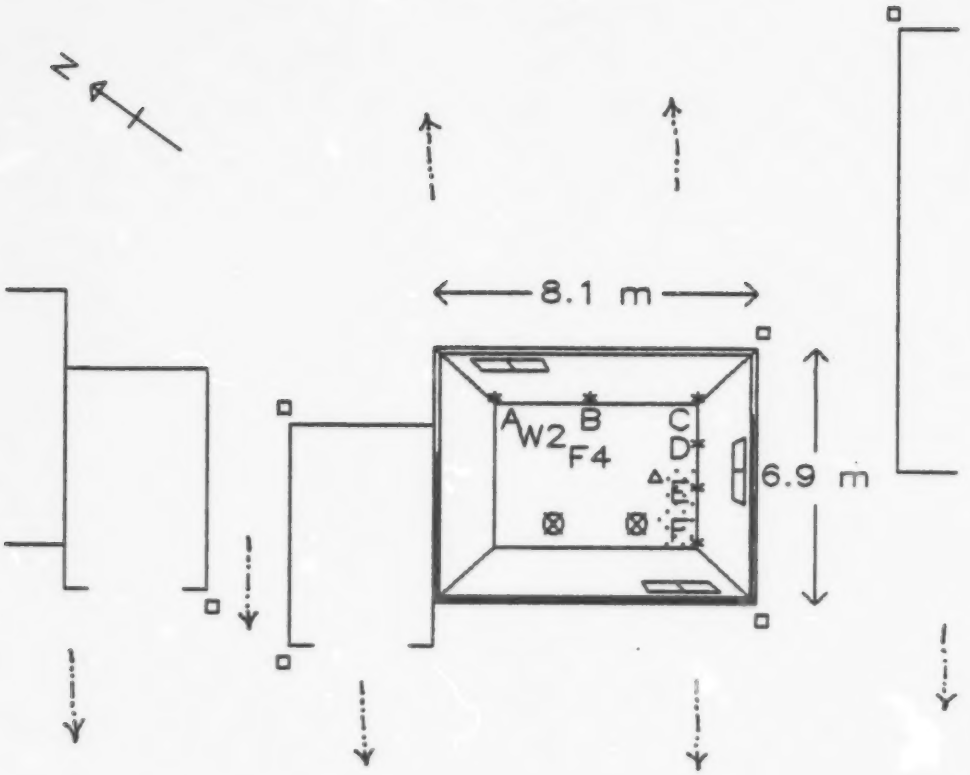


# 10	15 August 1987, 9:00–12:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
– – –	Approx. wall surface location corresponding to dewpoint of basement air
Air Temps	Basement 19.2, outdoors 18.1 (Celsius)
Humidity Ratio	Basement 0.0100 (kg moisture/kg dry air) Outdoors 0.0117; day's mean outdoors 0.0119
Comment	Wall surface temperature in SE corner at floor 15.8 C

HOUSE # 10: BASEMENT AIR VS OUTDOOR AIR

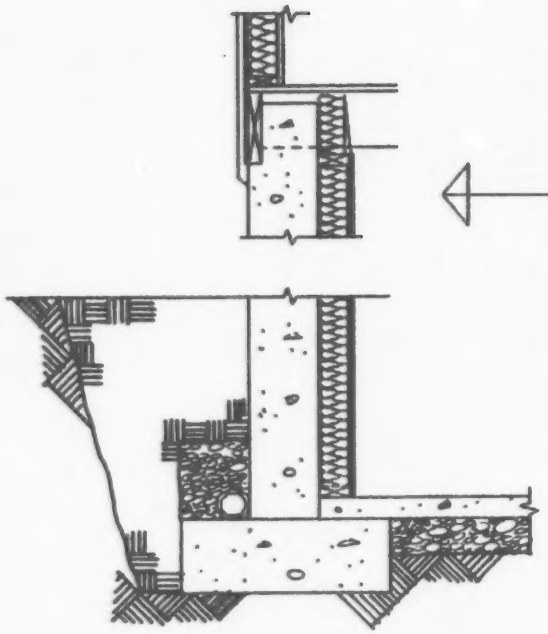


HOUSE # 11



# 11	Two–storey constructed in 1954 Some basement partitions; doorways normally open
▬▬	Insulated/uninsulated portion of concrete wall
▫/▫⟶	Downspout without/with extension
-·-·-·→	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←--⊕	Sump and discharge
▾/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F4	Nat. gas f/a furnace, pulse–condensing type, outdoor combustion air supply
W2	Standard electric DHW heater
⁘	Damp surface with efflorescence July–August 1987
Mech. Vent'n	No room exhaust fans Bas't clothes dryer vented outdoors via bas't wall

HOUSE # 11

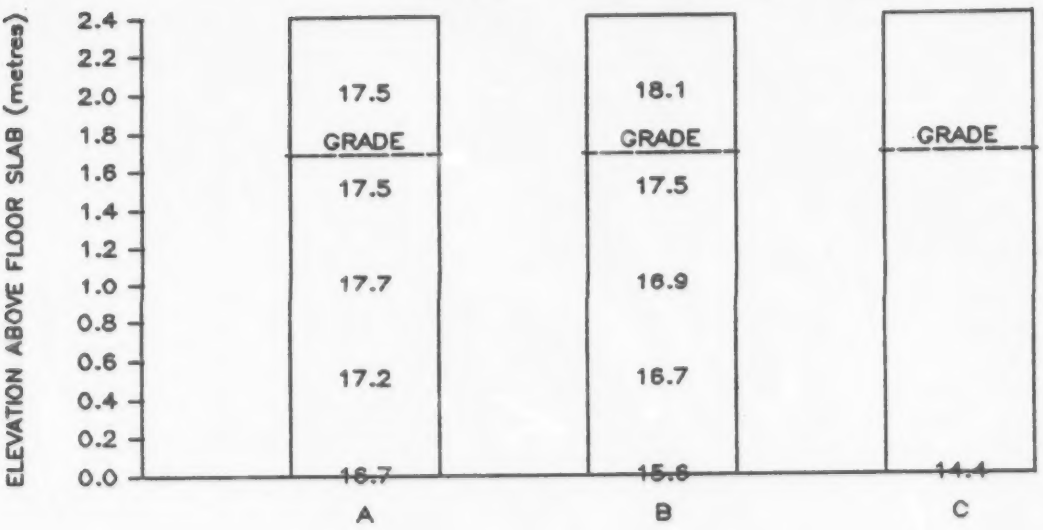


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 225 mm reinforced concrete wall
- RSI 1.2 batt insulation, kraft-faced
- 38x89 mm studs @ 400 mm O.C.
- Plywood panelling

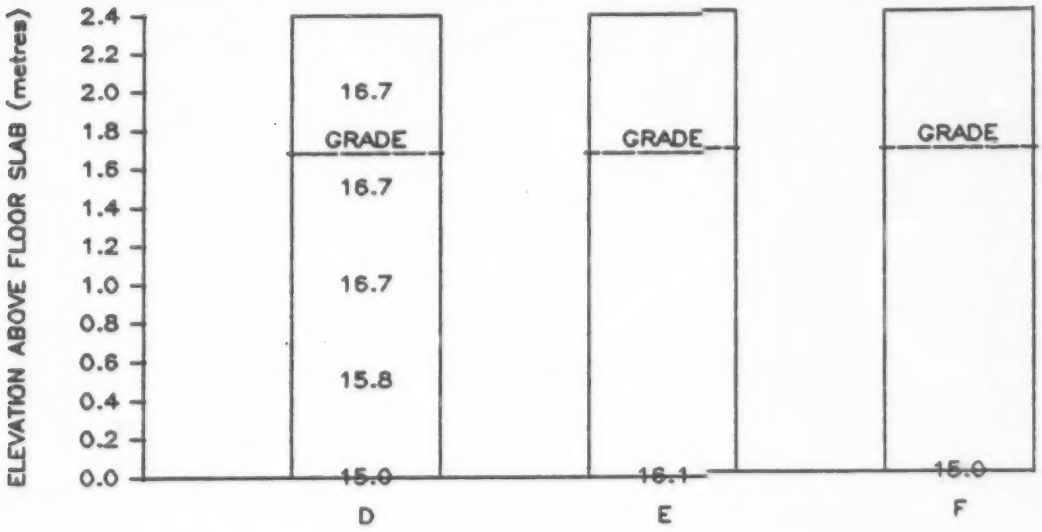
A.11.2

WALL SURFACE TEMPERATURES, HOUSE # 11

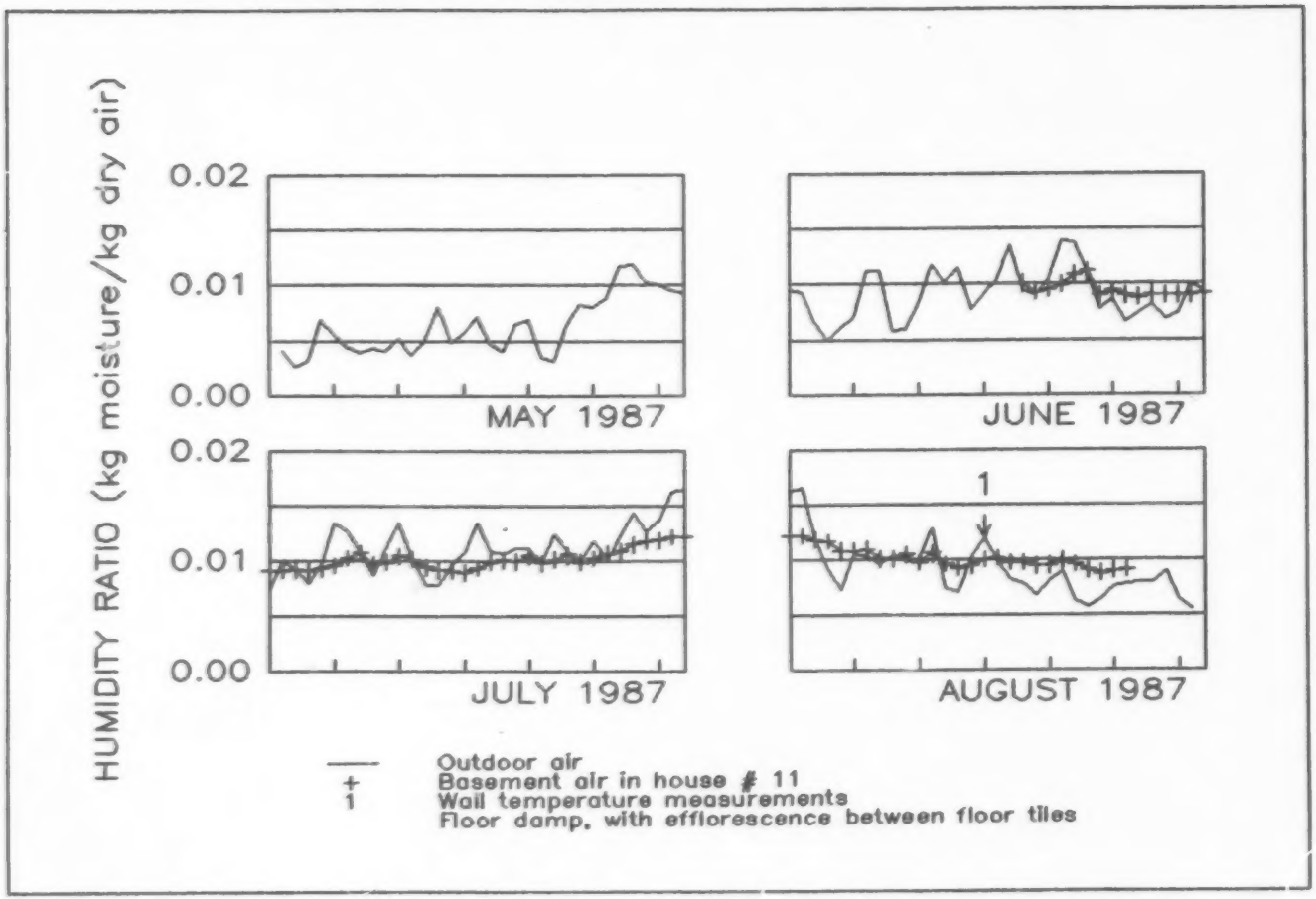


# 11	15 August 1987, 14:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
– – –	Approx. wall surface location corresponding to dewpoint of basement air
A	NE corner (behind DHW tank); bare wall
B	3.4 m S of NE corner; bare wall
C	SE corner; bare wall
D	0.9 m W of SE corner; bare wall
E	Approx. midpoint of S wall, at floor; wall insulated
F	SW corner, at floor; wall insulated
Air Temps	Basement 19.2, outdoors 20.3 (Celsius)
Humidity Ratio	Basement 0.0098 (kg moisture/kg dry air) Outdoors 0.0146; day's mean outdoors 0.0119
Comment	Area near SW corner is damp each summer

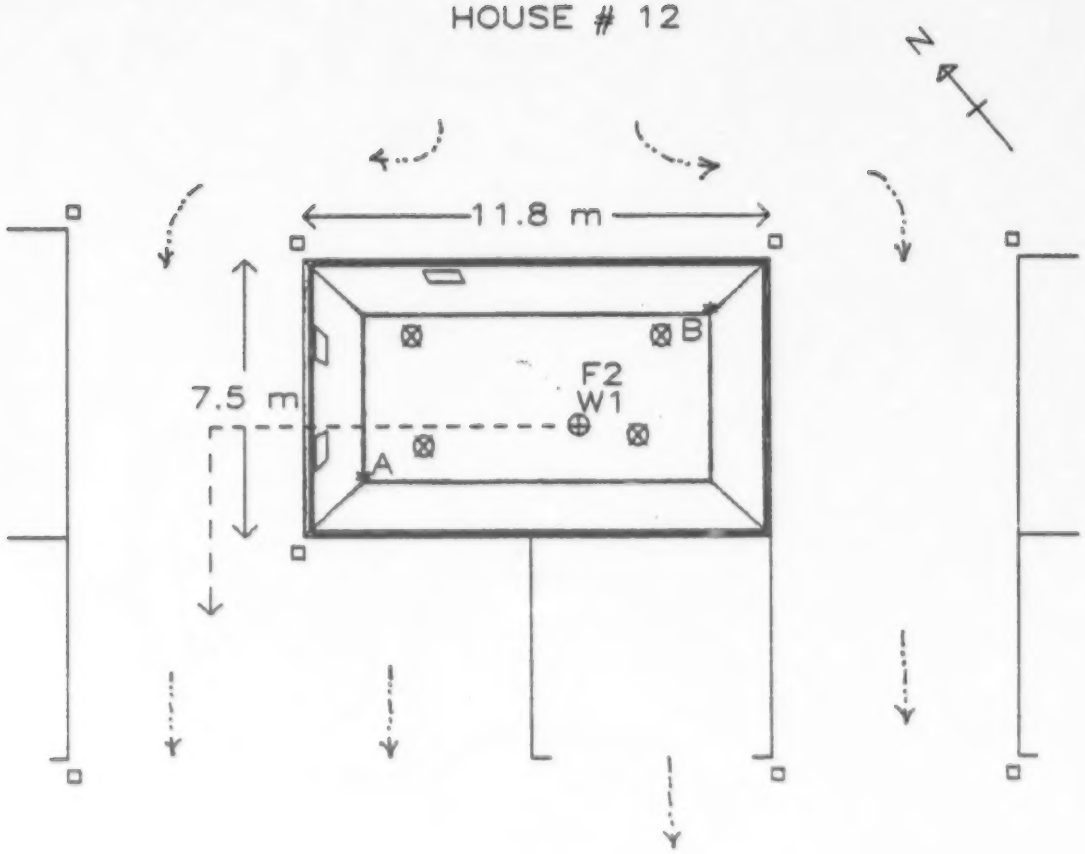
WALL SURFACE TEMPERATURES, HOUSE # 11



HOUSE # 11: BASEMENT AIR VS OUTDOOR AIR

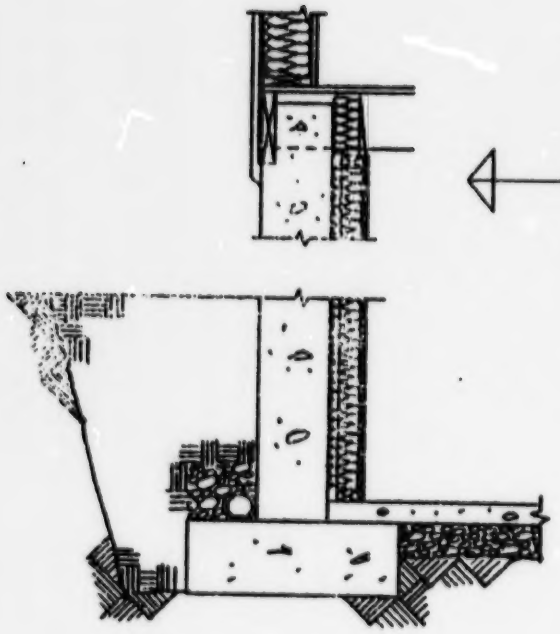


HOUSE # 12



# 12	Two–storey constructed winter–spring 1987 Bas't separable from upper level by interior door
▬▬	Insulated/uninsulated portion of concrete wall
o/o⟶	Downspout without/with extension
–··–→	Site surface drainage
O/⊠	Bas't supply air outlet without/with damper
←- -●	Sump and discharge
•/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F2	Nat. gas f/a furnace, spark ignition, vent damper
W1	Standard nat. gas DHW heater
	Wetted surface 26 August 1987
Mech. Vent'n	3 bath fans and 1 kitchen fan ducted to outdoors via exterior walls or attic Main floor clothes dryer vented outdoors via bas't wall Undampered fresh air intake to return air system Main floor fireplace

HOUSE # 12

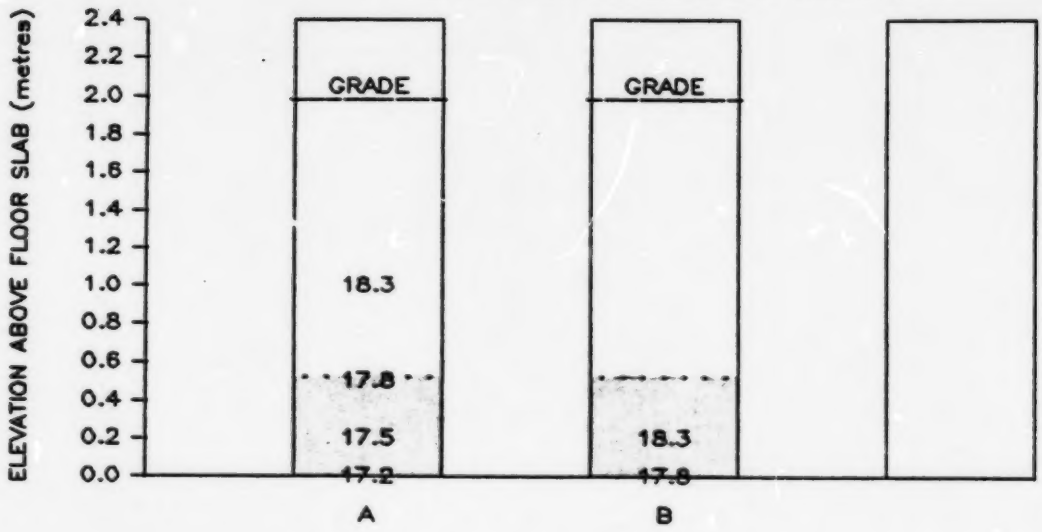


FOUNDATION WALL CONSTRUCTION

- Parging
- Dampproofing
- 200 mm reinforced concrete wall
- RSI 2.1 batt insulation
- 38x64 mm studs @ 400 mm O.C. set back 25 mm from concrete wall
- 6 mil polyethylene film stapled to studs and loosely where lapped and along bottom and top plates, and to sides of floor joists and underside of subfloor (no caulk used)
- 13 mm drywall

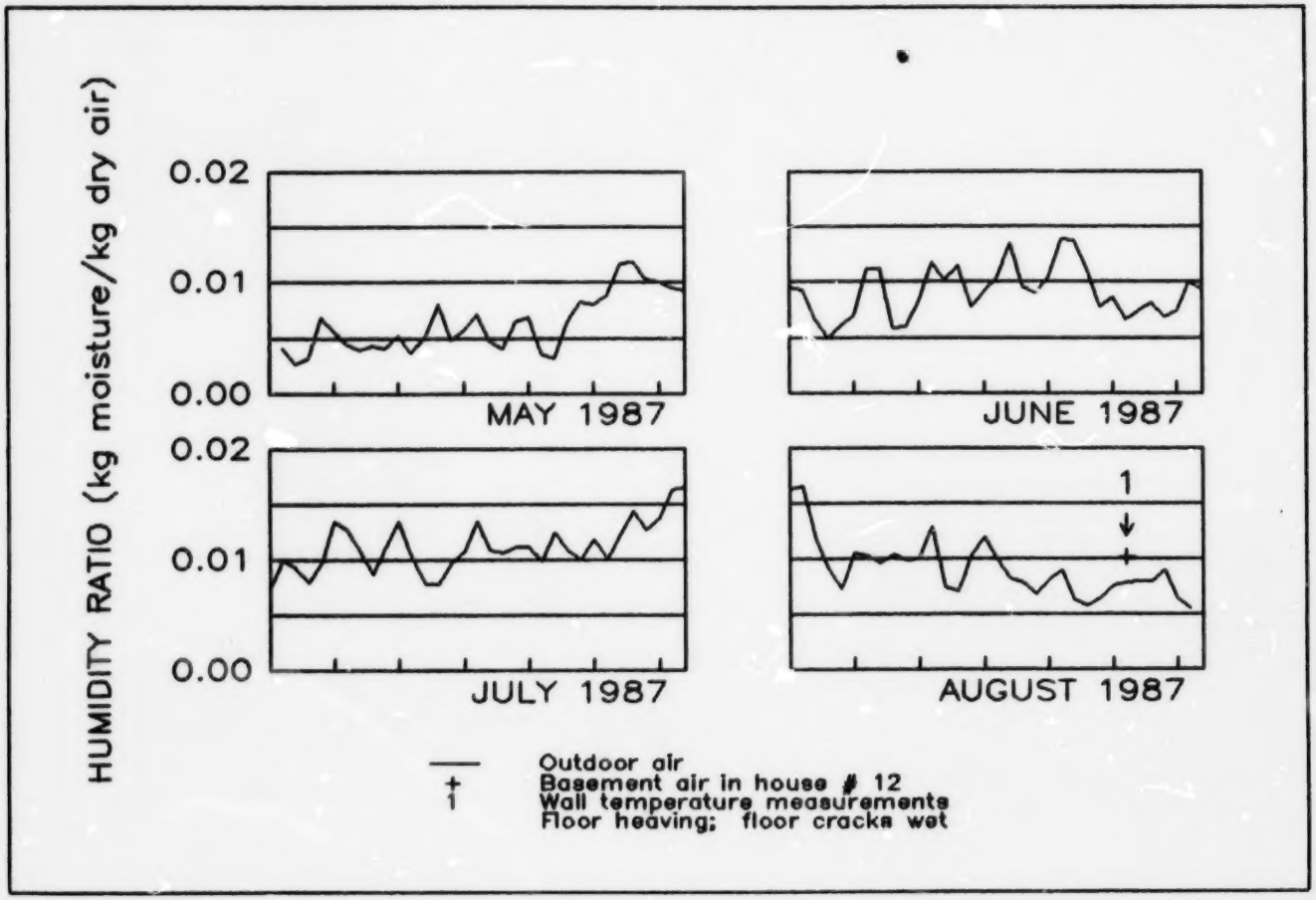
A.12.2

WALL SURFACE TEMPERATURES, HOUSE # 12

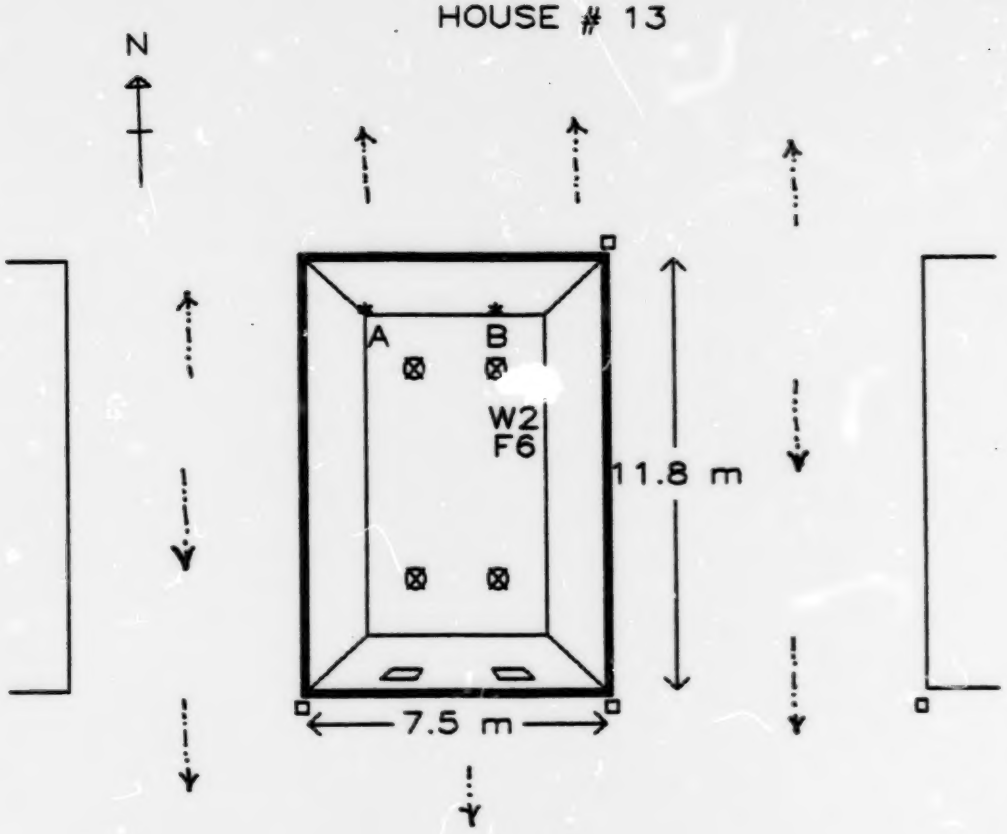


# 12	26 August 1987, 15:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
- - -	Approx. wall surface location corresponding to dewpoint of basement air
A	SW corner
B	NE corner
Air Temps	Basement 16.7, outdoors 21.4 (Celsius)
Humidity Ratio	Basement 0.0098 (kg moisture/kg dry air) Outdoors 0.0075; day's mean outdoors 0.0078
Comment	Basement flooded during spring melt, sump pump failed 0.3 to 0.6 m of standing water later pumped out Drywall and insulation removed, heaters used to accelerate drying; in July and August condensation has recurred, floor slab is heaving due to water in gravel base over expansive clay; floor cracks wet

HOUSE # 12: BASEMENT AIR VS OUTDOOR AIR

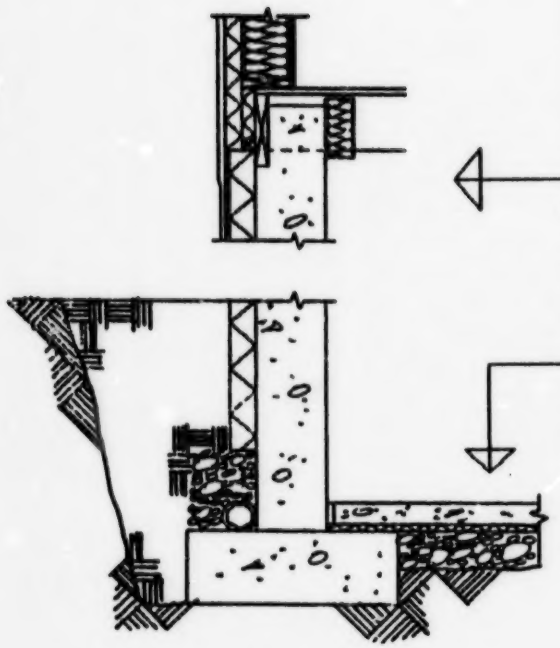


HOUSE # 13



# 13	Raised bungalow constructed winter 1986 Exterior basement insulation
▬▬	Insulated/uninsulated portion of concrete wall
□/□⟶	Downspout without/with extension
- - - - ⟶	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←- - -⊕	Sump and discharge
▼/▲	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F6	Electric baseboard heating and integrated electric space heating, water heating, and mechanical ventilation system
W2	Supplementary standard electric DHW heater
▒	Wetted surface
Mech. Vent'n	Exhaust-only system with heat recovery Bas't clothes dryer vented outdoors via bas't wall

HOUSE # 13



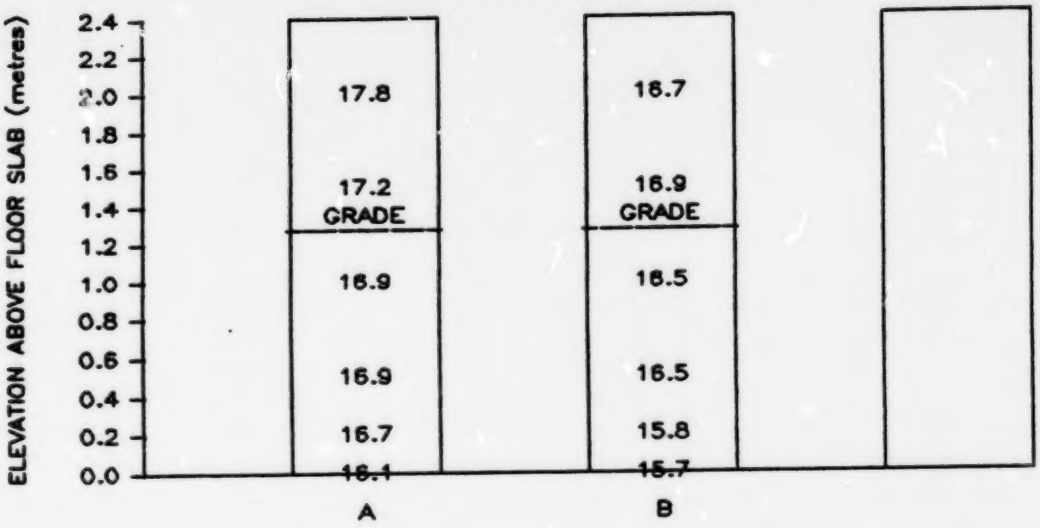
FOUNDATION WALL CONSTRUCTION

- Parging
- 13 mm p.t. plywood
- 75 mm glass fibre basement cladding
- Dampproofing
- 200 mm reinforced concrete wall

BASEMENT FLOOR CONSTRUCTION

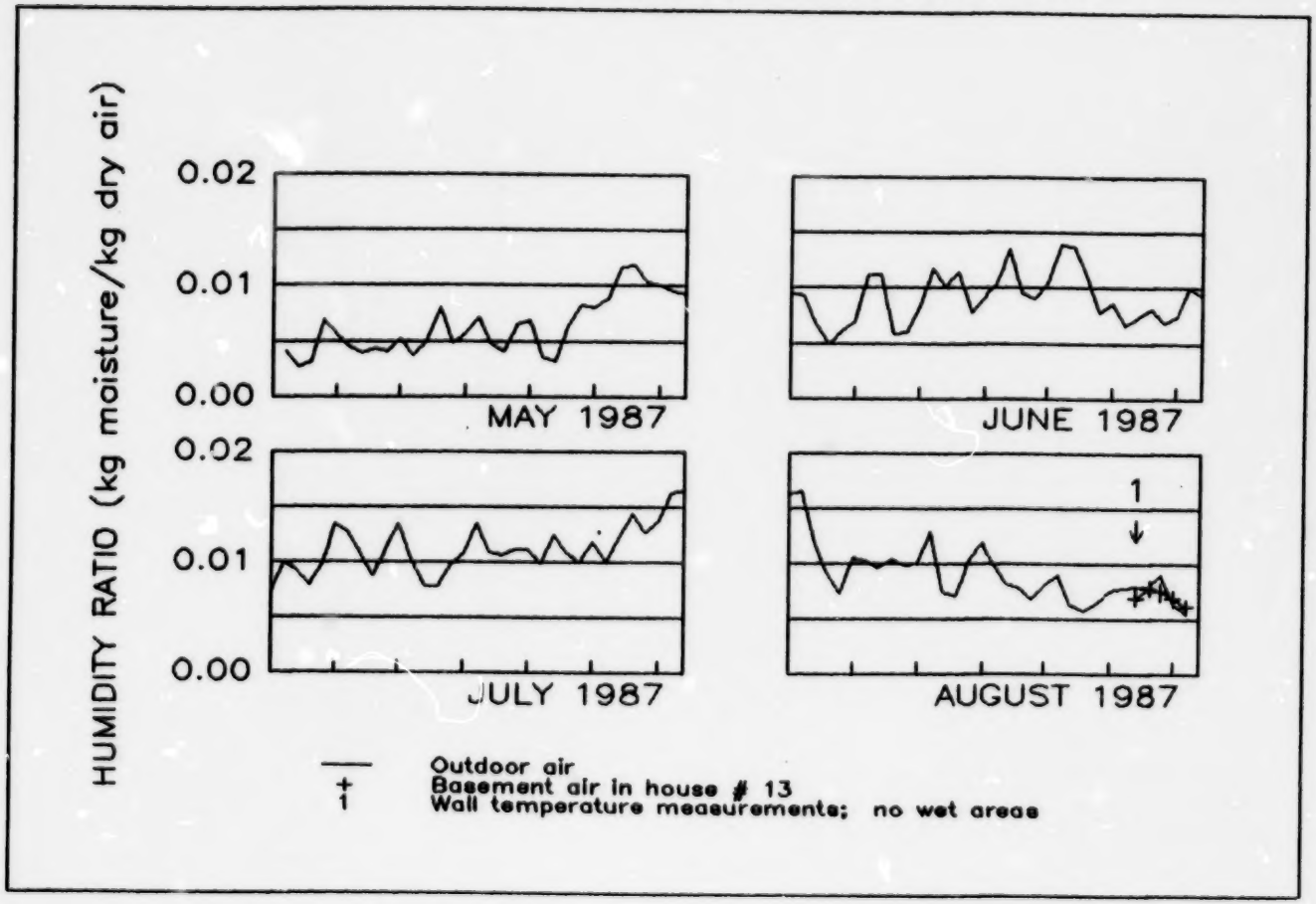
- 75 mm concrete slab
- 25 mm glass fibre exterior cladding (air barrier removed)
- 125 mm gravel

WALL SURFACE TEMPERATURES, HOUSE # 13

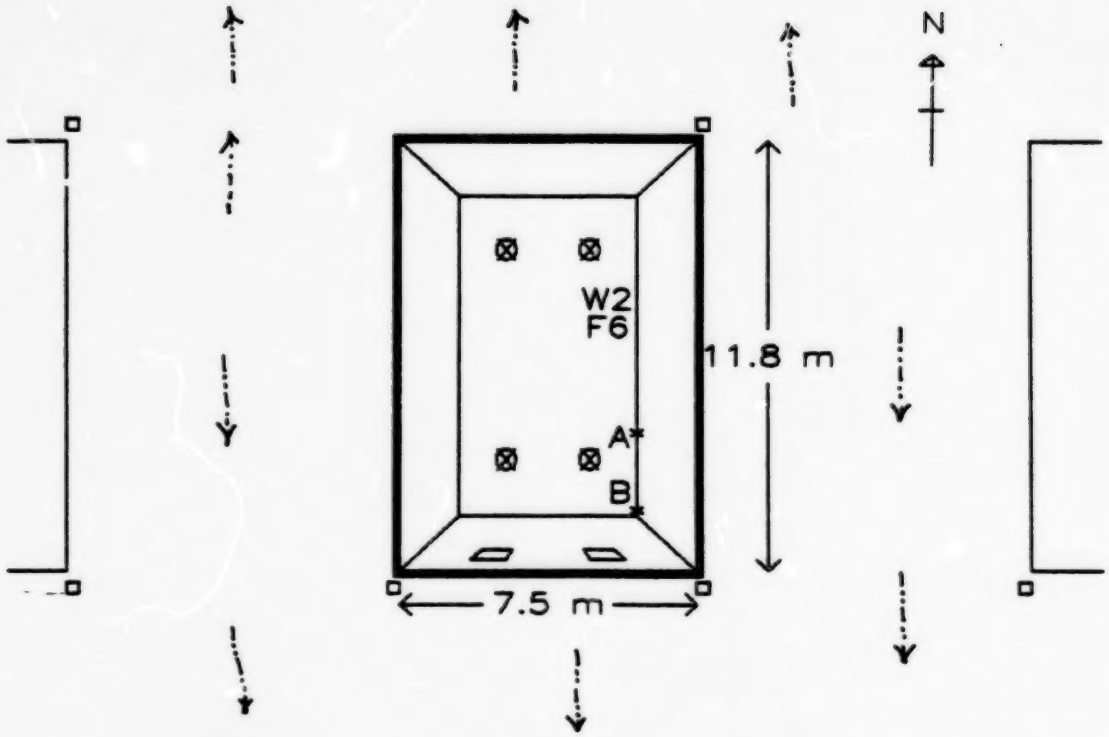


# 13	26 August 1987, 14:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
– – –	Approx. wall surface location corresponding to dewpoint of basement air
A	NW corner
B	2.3 m W of NE corner
Air Temps	Basement 19.2, outdoors 21.4 (Celsius)
Humidity Ratio	Basement 0.0078 (kg moisture/kg dry air) Outdoors 0.0075; day's mean outdoors 0.0078
Comment	Exterior insulation; wall surfaces bare on interior

HOUSE # 13: BASEMENT AIR VS OUTDOOR AIR

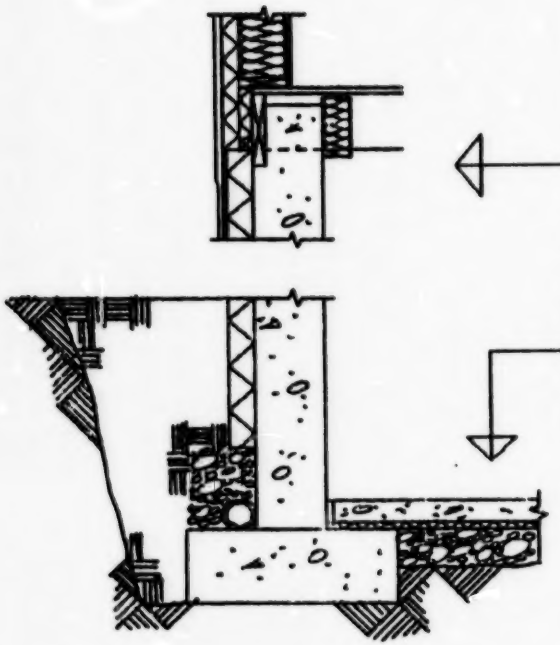


HOUSE # 14



# 14	Raised bungalow constructed winter 1985 Exterior basement insulation
▬▬	Insulated/uninsulated portion of concrete wall
o/o⟶	Downspout without/with extension
-·-·-·→	Site surface drainage
○/⊗	Bas't supply air outlet without/with damper
←---●	Sump and discharge
▾/▴	Position of dehumidifier/recording hygrothermograph
*A	Wall surface temperature measurement station
▱	Openable window
F8	Electric baseboard heating and integrated electric space heating, water heating, and mechanical ventilation system
W2	Supplementary standard electric DHW heater
▒	Wetted surface
Mech. Vent'n	Exhaust-only system with heat recovery Bas't clothes dryer vented outdoors via bas't wall

HOUSE # 14



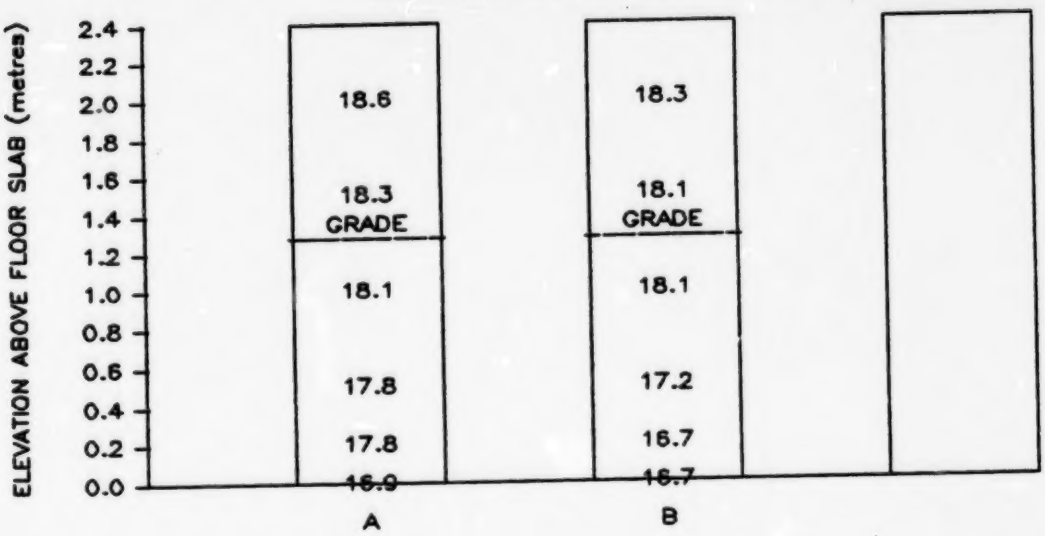
FOUNDATION WALL CONSTRUCTION

- Parging
- 13 mm p.t. plywood
- 75 mm glass fibre basement cladding
- Dampproofing
- 200 mm reinforced concrete wall

BASEMENT FLOOR CONSTRUCTION

- 75 mm concrete slab
- 25 mm glass fibre exterior cladding (air barrier removed)
- 125 mm gravel

WALL SURFACE TEMPERATURES, HOUSE # 14



# 14	27 August 1987, 13:00 CST
	Wetted surface
21.3	Concrete surface temperature (Celsius)
- - -	Approx. wall surface location corresponding to dewpoint of basement air
A	3.2 m N of SE corner
B	SE corner
Air Temps	Basement 20.0, outdoors 23.3 (Celsius)
Humidity Ratio	Basement 0.0084 (kg moisture/kg dry air) Outdoors 0.0080; day's mean outdoors 0.0080
Comment	Exterior insulation; wall surfaces bare on interior

HOUSE # 14: BASEMENT AIR VS OUTDOOR AIR